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GEOLOGY OF THE PEGMATITES AND ASSOCIATED ROCKS OF MAINE

INCLUDING

FELDSPAR, QUARTZ, MICA, AND GEM DEPOSITS

BY

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GEOLOGY OF THE PEGMATITES AND ASSOCIATED ROCKS OF MAINE.

By Edson S. Bastin.

INTRODUCTION.

The field studies which form the basis of this report were made by the writer during July and August, 1906, under the general supervision of George Otis Smith, of the United States Geological Survey. The writer wishes to acknowledge the valuable advice and kindly assistance of the late Prof. Leslie A. Lee, state geologist of Maine, at the time the field work for this report was done, and the cordial cooperation of many persons interested in the deposits concerned, without whose aid these studies would not have been possible.

The expenses of the work were shared equally by the Survey Commission of the State of Maine and the United States Geological Survey.

On account of the brief time at the writer's disposal in the field, it was impossible to attempt anything like a prospecting of the whole State for the minerals here considered. Visits were made, however, to nearly all of the localities which had been or are at the present time operated commercially, and numerous observations were made on the geology of the intervening territory.

With the exception of a few of the gem deposits, most of the minerals here described have been exploited commercially only within the past fifty years. They belong neither to that class of natural resources, such as coal and limestone, which are useful to a pioneer civilization, nor (with the exception of the gems) to the class of highly precious materials which attract the explorer or the adventurer. Their utilization was possible only after a very considerable development in the arts and industries of New England had taken place.

DEFINITION OF PEGMATITE.

The granite-pegmatites, in which are found feldspar, quartz, mica, and gem minerals, are composed of the same mineral constituents as the ordinary granites of the State, and differ from these principally in their greater coarseness and in their very uneven texture.

Among themselves the granite-pegmatites differ greatly in coarseness, some being little coarser than ordinary coarse-grained granite and others showing single masses of feldspar or of quartz 20 feet in diameter. Their distinguishing feature is, therefore, not coarseness of grain but extreme irregularity of grain. In a granite different grains of the same mineral species differ in size, but usually only within rather narrow limits. In a pegmatite, on the other hand, they appear to differ without limit, a crystal of feldspar an inch across perhaps having a neighbor which is several feet across. This textural feature is illustrated on a microscopic scale in Plate II, which is a reproduction of a photomicrograph of fine-grained aplitic pegmatite exposed in the river bed at Lewiston.

Pegmatite usually forms dikes or sill-like masses in areas occupied principally by rocks of other kinds. (See p. 11.)

GEOGRAPHIC DISTRIBUTION.

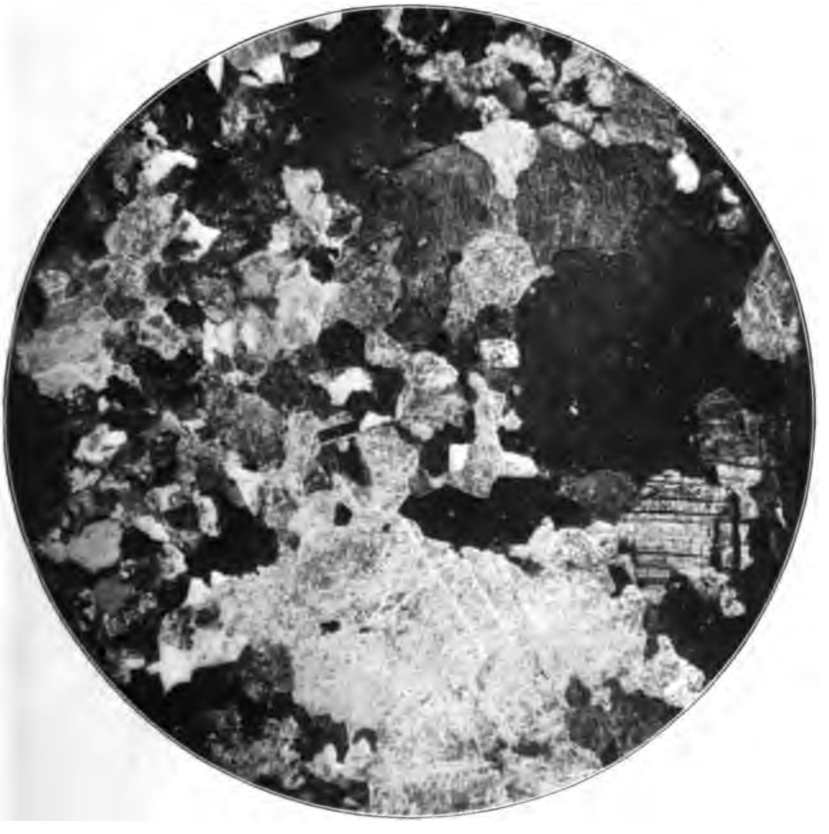
Pegmatites occur throughout the Appalachian Mountain region from Alabama to New York and thence northeastward into Connecticut, Massachusetts, New Hampshire, and Maine. In most of these States they have been worked commercially to a greater or less extent. In Maine the commercial deposits are confined largely to Cumberland, Sagadahoc, Lincoln, Androscoggin, and Oxford counties, though pegmatites also occur to some extent in Franklin, Kennebec, Waldo, Knox, Hancock, and Washington counties. Their general distribution, as well as that of the granites, is shown on Plate I, on which are also indicated the localities which have been worked commercially for various pegmatite minerals.

Excellent opportunities for studying the character and relationships of the pegmatites are afforded by many of the quarry openings, by numerous glaciated rock surfaces, and by almost continuous exposures along the seashore. The shore in the Boothbay region especially is an excellent field for study.

GEOLOGY.

BORDERING ROCKS.

The geologic relations of the Maine pegmatites show that most of them are distinctly intrusive into the surrounding rocks, although the conditions of intrusion are somewhat varied; and that in origin they are closely connected with the granites (p. 27). The rocks



MICROPHOTOGRAPH OF FINE-GRAINED PEGMATITE FROM RIVER BED AT LEWISTON.
MAGNIFIED ABOUT 34 TIMES.

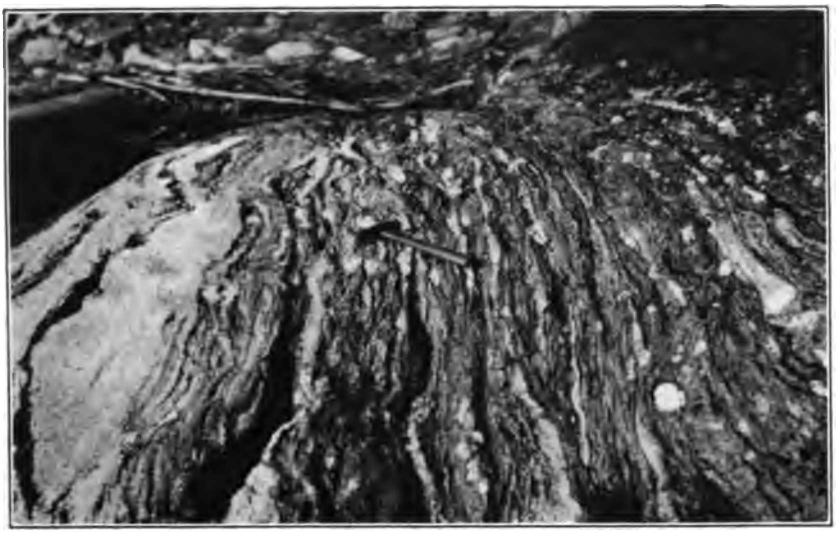
Illustrates the extreme irregularity characteristic of the commonest type of pegmatitic texture.

A. HIGHLY INCLINED DIKE OF PEGMATITE IN SCHISTS AT PEMAQUID POINT, MAINE.

Showing characteristic swelling and pinching of dikes

B. FLAT-LYING OR SILL-LIKE DIKE IN PEGMATITE INTRUDING GENTLY INCLINED SEDIMENTARY SCHISTS. BED OF ANDROSCOGGIN RIVER, BETWEEN RAILWAY AND HIGHWAY BRIDGES, AUBURN-LEWISTON, MAINE.

Showing lenslike form characteristic of many of these pegmatite masses.



A. INTIMATE INJECTION OF SEDIMENTARY SCHISTS BY PEGMATITE, FORMING AN INJECTION GNEISS.

South shore of McMahon Island.

B. PEGMATITE MASS, SENDING OFF STRINGERS OF PEGMATITE AND QUARTZ INTO THE BORDERING SCHIST AND THUS FORMING AN INJECTION GNEISS.

Bay Point Peninsula, Georgetown.

into which they are intruded are in some places granites, but are generally foliates,[a] either schist or gneiss. The foliates are in many places dynamically metamorphosed sediments, but in others are unquestionably primary.

PEGMATITES IN FOLIATED ROCKS.

General statement.—Though showing minor irregularities of form, most of the pegmatite masses in the foliated rocks are of sheetlike character and lie parallel or nearly parallel to the schist or gneiss folia. If the foliates are steeply inclined the pegmatite exhibits a dikelike form (Pl. III, *A*); if they are flat-lying the pegmatite mass assumes a sill-like form (Pl. III, *B*).

Another feature highly characteristic of pegmatite masses in foliates is their tendency to swell and thin along their trend so as to form virtually a series of connected lenticles. (See fig. 1.)

The contact between pegmatite and foliate is in nearly all areas very sharp, whether the pegmatite lies parallel to or cuts across the folia and whether its mass is large or small. In many places (see Pl. IV, *A*, *B*) the pegmatitic intrusion is so intimate that the bordering schist becomes an injection gneiss. Such gneisses are very characteristic features of many districts in southern Maine, particularly in Oxford County.

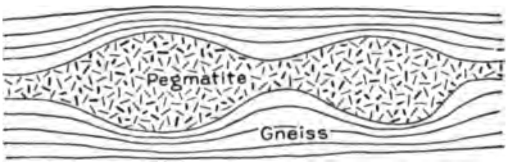


FIGURE 1.—Pinch and swell structure in pegmatite dike.

Sedimentary foliates.—The sedimentary origin of many of the foliates associated with the pegmatites is shown beyond question at a number of localities by the preservation of distinct bedding in the more quartzose layers. Notable examples are the schists exposed at the Graphite mine at Crocker Hill (near Paris) and at many places in Auburn village and studied particularly at the new reservoir site, where the layers in which bedding is preserved are shown on microscopic study to be micaceous quartzite.

Since the pegmatite frequently cuts across the folia of the sedimentary schists and does not notably change the latter along the contacts, it is plain that the foliation of the schists is not a contact effect of the pegmatite intrusion. It is to be attributed mainly to regional metamorphism previous to the pegmatite intrusions. Since these foliates bear no traces of fossils, their age is indeterminate, but certain of them may be correlated with the Penobscot for-

[a] The term "foliates" was proposed by the writer (Jour. Geology, vol. 17, p. 449) as a convenient comprehensive term to include all rocks showing foliated structures other than bedding planes. Its use avoids frequent repetition of the terms schists and gneisses, and avoids any postulate as to the primary or secondary character of the foliated structure.

mation of the Penobscot Bay region.[a] As the last great dynamic metamorphism which affected southern and central Maine took place probably near the close of Ordovician time, these dynamically metamorphosed sediments are probably not younger than Ordovician.

Igneous foliates.—Others of the foliated rocks with which the pegmatites are associated are probably primary or flow foliates; that is, igneous rocks that owe their foliated structure to differential movement within their mass before complete solidification. To this class probably belong many of the foliates in the Boothbay Harbor region and about Brunswick and Topsham. Many of them are very similar in their general appearance to foliates of sedimentary origin but upon microscopic study are found to be indistinguishable in mineral composition from igneous rocks. One of the most instructive exposures of a foliate of this type occurs on the east shore of St. George River, near the extreme southern edge of the Rockland quadrangle, where porphyritic granite of normal composition, with feldspar phenocrysts from one-half to three-fourths of an inch in length, contains a number of elongated parallel lenses of much finer grained rock of dioritic composition. (See Pl. V, *A*.) The largest of these lenses is about 6 feet long and 1 foot wide. The inclosing granite shows a decided grain parallel to the direction of elongation of the lenses, and in other similar occurrences in this region the feldspar phenocrysts of the bordering granite show a tendency toward orientation with their long axes parallel to the axes of the basic lenses. Within a few rods of this exposure occurs another which presents the appearance shown in Plate V, *B*, the light-colored bands having about the texture and composition of normal granite and the darker bands being quartz diorite similar to the lenses at the exposure shown in Plate V, *A*.

Under the microscope the dioritic and granitic bands are both seen to be feldspathic and of interlocking granular texture without any cataclastic structures. The basic bands, however, besides being finer grained than the others, contain a much larger percentage of green hornblende and a smaller percentage of quartz. Both phases contain abundant titanite in grains, many of which show well-defined crystal form. The feldspar in both has the composition of oligoclase-andesine.

It seems evident that the gneiss of Plate V, *B*, represents merely the next step of the process of combined flowage and magmatic differentiation which developed the relations shown in Plate V, *A*, and that the two represent two stages in the making of a flow gneiss. At the time when the whole mass was in a molten condition the basic portions were presumably more fluid than the acidic portions, and the process is probably to be regarded as an intimate intrusion of

[a] Penobscot Bay folio (No. 149), Geol. Atlas U. S., U. S. Geol. Survey, 1907.

A. LENSES OF QUARTZ DIORITE IN PORPHYRITIC GRANITE. PROBABLY THE RESULT OF COMBINED FLOWAGE AND BASIC SEGREGATION ABOUT MANY CENTERS.

East shore of St. George River, near south border of Rockland quadrangle.

B. COARSE IGNEOUS GNEISS OF ALTERNATE LAYERS OF GRANITE AND QUARTZ DIORITE.

Same locality. Showing a further step in the process illustrated above.

the more viscous by the less viscous portions of the same magma when both were under lateral compression.

At an old road-metal quarry in the city of Brunswick schists of probable igneous origin are also well exposed in association with pegmatite. The schists show very even and regular foliation and an alternation of broad light-gray layers with narrower ones which are dark gray to nearly black. The lighter bands are seen under the microscope to be a hornblende granite of interlocking granular texture and without cataclastic structures. The foliated structure is due to a greater abundance of hornblende along certain planes than along others and to subparallel elongation of the hornblende grains. The dark-gray phases of the schist have the mineral composition of quartz diorite, the feldspar being largely andesine. A few bands up to one-eighth inch or so across are a more coarsely crystalline association of quartz with a little feldspar. These schists carry none of the minerals, such as staurolite and andalusite, frequently observed in metamorphosed sediments, and though their derivation by metamorphism from arkoses or graywackes is conceivable it is not probable. The pegmatite associated with these schists locally cuts across their foliation, but in other places grades into them so completely as to suggest that the schist was not completely solidified at the time the pegmatite was intruded.

Here and at a number of other localities a slight foliation parallel to the schist folia is visible in some of the pegmatites; it suggests a slight flowing movement in the schist subsequent to the intrusion of the pegmatite. The thickening of the schist folia opposite the nodes of pegmatite dikes and their thinning opposite the bulges (see fig. 1) is also indicative of flowing movements in the schists at the time the pegmatite was intruded. Many of the pegmatite bodies associated with the primary flow foliates are probably to be regarded as intrusions under high pressure of a less viscous into a more viscous magma.

PEGMATITES IN MASSIVE GRANITES.

The relationships exhibited at a number of localities between the pegmatites and the granites throw much light on the origin of the former. Of broad significance is the fact that granite is present in all of the districts in which pegmatite occurs. The reverse relation also holds, though to a lesser degree. The similarity in mineral composition between the granites and the pegmatites will be considered later.

The detailed relationships existing between the two rocks are various. At the Woodside quarry in the town of Brunswick, 2½ miles southeast of Hillside station, a rather fine-grained muscovite-biotite granite has been quarried for flagging and underpinning. In it the pegmatite often forms lens-shaped or wholly irregular bodies, the two rocks being characterized by the same minerals and grading into each other in the most gradual and complete manner. In such cases there can be no question that the two rocks crystallized from the same magma and that the pegmatitic masses are to be regarded as segregations within the granite. In other places, however, even at this same quarry, pegmatite, which in general appearance and mineral composition is indistinguishable from that described above, forms sharp-walled dikes in the granite.

An exposure on the shore of the first point west of Boothbay Harbor shows a dike of fine-grained granite 1½ feet wide cutting schist and pegmatite. A few feet farther north the same granite dike is itself cut by pegmatite that is wholly similar in appearance to the pegmatite which the granite intrudes. These relations show that the pegmatites are not precisely contemporaneous. Since, however, there is no evidence here or elsewhere in Maine of very wide divergence in the age of different pegmatites or different granites (see p. 15), the exposure also shows the broad contemporaneity of granite and pegmatite.

On the island of Southport, on the shore near the south entrance of Townsend Gut, the schist, granite, and pegmatite are associated in the manner shown in figure 2. Both are distinctly intrusive, the schist contacts being everywhere sharp and in many places very ragged. The main mass of the intrusion is granite of normal texture, but the narrower branches sent off by the granite parallel to the foliation of the schists become typical pegmatite a short distance from the granite mass. The gradation between the two rocks is gradual and complete.

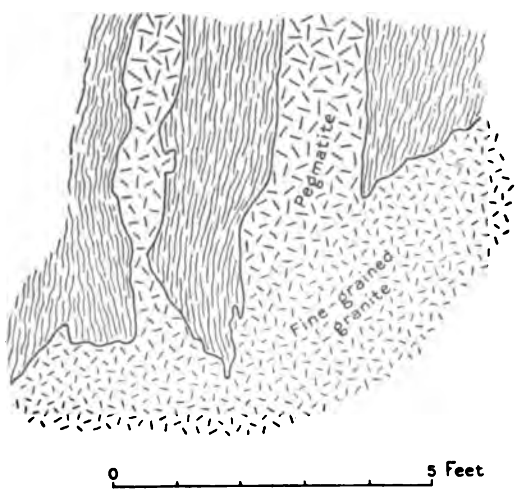


FIGURE 2.—Gradation of granite into pegmatite, Boothbay Harbor.

Under the microscope the granite shows an interlocking granular texture and consists principally of quartz and microcline, with minor amounts of orthoclase, of biotite altering to chlorite, and of muscovite, in part primary and in part a product of feldspar alteration. Micrographic granite is present in small amounts, as are scattered small grains of oligoclase. The minerals of the pegmatite are identical with those of the granite but occur in much larger crystals, with much greater range in size among individuals of the same mineral species. Oligoclase and micrographic intergrowths of quartz and feldspar are also more abundant in the pegmatite than in the granite.

For detailed descriptions of other instances of gradations or close relationship between granite and pegmatite the reader is referred to locality descriptions of the Rumford Falls region (p. 94), Stow (p. 102), Edgecomb (p. 64), Boothbay Harbor (p. 67), and the South Waterford mica mine (p. 103).

The granites and associated pegmatites are the youngest known rocks occurring in notable abundance within the State. Here and there, however, they are cut by younger small dikes of diabase, usually aphanitic and sharp walled. Usually these occur only as individuals, but on the shore of Keewaydin Lake (Lower Stone Pond), near the village of East Stoneham, schist and associated pegmatite are intruded by a remarkable network of fine-grained diabase. (See Pl. XVI, *A*.)

AGE.

The field studies in Maine have afforded no evidence of great diversity in age among the pegmatite deposits. Although all of them are not strictly contemporaneous, it seems probable that all were formed within the limits of a single period of geologic time. As it has been shown (p. 27) that the pegmatites are broadly contemporaneous with the granites with which they are invariably associated, the age of the pegmatites may be inferred from that of the granites.

The evidence thus far available indicates that all of the granites of the State are of approximately the same geologic age. In the Penobscot Bay region granite is intrusive in rocks of Silurian (Niagaran) age.[a] In the Perry Basin,[b] in the extreme eastern part of the State, granite pebbles are absent from the late Silurian sediments but are present in the conglomerate of the Perry formation, which is probably of Upper Devonian age. The granites were therefore intruded in late Silurian or in Devonian time, and the pegmatites are also probably of that age.

GENERAL CHARACTER.

MINERAL AND CHEMICAL COMPOSITION.

Mineral constituents.—The pegmatite deposits in all parts of the State show great similarity in their principal minerals, although exhibiting notable differences in their minor constituents. Essentially they are coarse granites, their principal light-colored constituents being potash and soda feldspars, quartz, and muscovite,

[a] Penobscot Bay folio (No. 149), Geol. Atlas U. S., U. S. Geol. Survey, 1907.

[b] Smith, G. O., and White, David, Geology of the Perry Basin: Prof. Paper U. S. Geol. Survey No. 35, 1905.

and their principal dark-colored constituents black mica (biotite) and black tourmaline. In pegmatites in which black mica is abundant black tourmaline is almost always rare or absent, and vice versa. Accessory constituents present in almost all pegmatites are garnet, magnetite, and green opaque beryl. Accessory minerals present only in certain pegmatites number over fifty species, the most important probably being lepidolite or lithium mica; amblygonite; spodumene; blue, green, and pink tourmaline; transparent green, pale-blue, or golden beryl; colorless to amber-colored topaz; and rose and amethystine quartz.

The following minerals have been reported from the pegmatite deposits of Maine:

Albite.—Common in many of the pegmatite deposits; in some places massive, but usually occurring as the white lamellar variety clevelandite. Especially abundant in gem-bearing pegmatites.

Allanite.—Reported from pegmatite at Mount Apatite, in Auburn.

Amblygonite.—An original constituent of many of the pegmatite deposits, especially those bearing gem minerals.

Apatite.—Occurs as an original pegmatite constituent wholly inclosed by other minerals in many pegmatite deposits. The fine purple apatites of Mount Apatite, in Auburn, occur on the walls of pockets and were probably deposited by aqueous or pneumatolytic agencies during the latest stages of the pegmatite crystallization.

Arsenopyrite.—Reported from pegmatite at Mount Rubellite, in Hebron.

Autunite.—Occurs at the Dunton tourmaline mine in Newry, Oxford County, in crystals seldom over $\frac{1}{16}$ inch across, embedded in or lying between plates of clevelandite. Mostly decomposed. Found also at Harndon Hill, in Stoneham.

Bertrandite.—Occurs with herderite and hamlinite in cavities in pegmatite at Stoneham.

Beryl.—Translucent to opaque varieties, wholly inclosed by other constituents, occur in nearly all the coarser pegmatite bodies. A few crystals reach gigantic proportions. In a few coarse pegmatites transparent pale-green gem varieties (aquamarine) occur completely embedded or projecting from the walls of cavities.

Beryllonite.—Not found in place, but occurring in the soil in Stoneham. It is attached to typical pegmatite minerals and is plainly an original pegmatite constituent.

Biotite.—One of the abundant constituents of most of the pegmatites.

Calcite.—Not observed as an original pegmatite constituent, but occurs occasionally as a secondary deposit in fissures and cavities.

Cassiterite.—An original constituent in pegmatite at Paris, Hebron, Stoneham, and Auburn.

Childrenite.—Reported as an original constituent of pegmatite at Mount Rubellite, in Hebron, occurring in minute hair-brown prismatic crystals with amblygonite.

Chrysoberyl.—An original pegmatite constituent at a large number of localities, though nowhere abundant.

Clevelandite.—See Albite.

Columbite.—An original constituent of certain pegmatites. Present only in small amounts.

Cookeite.—Abundant as a coating in most of the pockets in the coarser pegmatites. Not an original constituent but secondary and due to water deposition.

Damourite.—Occurs at Mount Rubellite, in Hebron, as an alteration product of tourmaline. Also reported from Mount Apatite, in Auburn.

Emerald.—Gem beryl found in Maine is usually so pale that it is classed as aquamarine. One fractured crystal found by the writer at the Dunton mine in Newry could properly be classed as a pale emerald.

Feldspar.—One of the principal pegmatite minerals. See albite, orthoclase, and microcline.

Fluorite.—Small crystals occur as an original constituent in a few of the pegmatites, but in general fluorite is much rarer in the Maine pegmatites than in those of certain other regions.

Garnet.—A common constituent of most of the pegmatites. Frequently occurs in graphic intergrowth with quartz, muscovite, or feldspar. Garnet of gem clearness is extremely rare.

Graphite.—Absent from most of the Maine pegmatites. Occurs in pegmatite injected into sedimentary schists at a few localities.

Gummite.—Reported in minute particles from pegmatite at Mount Apatite, in Auburn. An alteration product of some uranium mineral.

Halloysite.—Reported from Mount Mica. Probably a decomposition product of feldspar.

Hamlinite.—Occurs sparingly at Stoneham, associated with herderite and bertrandite.

Hebronite.—See Amblygonite.

Herderite.—Found at Stoneham, Me., on quartz crystals in pockets in the pegmatite. Found sparingly in Hebron and Greenwood, at Mount Apatite in Auburn, and at Berry's quarry in Poland.

Kaolinite.—A decomposition product of feldspar. Common in pockets in the coarser pegmatites.

Limonite.—A secondary mineral in some pegmatites, resulting from the decomposition of other iron-bearing minerals.

Lepidolite.—Common in pegmatites which bear gem tourmalines.

Löllingite.—Occurs in narrow stringers cutting feldspar at Mount Mica, in Paris, as an original pegmatite constituent.

Magnetite.—Common in many pegmatites in well-developed step-crystals.

Microcline.—One of the commonest constituents in the pegmatites. Most of the potash feldspar present is microcline rather than orthoclase.

Mica.—See Biotite, Muscovite, and Lepidolite.

Molybdenite.—Abundant as an original constituent in granite and associated pegmatite at Catherine Hill in Hancock County, and reported in small amounts in similar rocks elsewhere. Reported from pegmatite in Auburn. Rare in most pegmatite bodies.

Montmorillonite.—Associated with cookeite and other secondary minerals in the pockets of several of the coarser pegmatite masses. A product of feldspar decomposition.

Muscovite.—One of the principal constituents in nearly all pegmatites.

Orthoclase.—Present with microcline in nearly all of the pegmatites, the two being commonly intergrown in the same crystal.

Phenacite.—Reported from pegmatite at Noyes's tourmaline mine in Greenwood.

Plumbago.—See Graphite.

Pollucite.—Occurs in pockets in pegmatite at Mount Rubellite in Hebron.

Pyrite.—An original constituent in many Maine pegmatites.

Pyrrhotite.—An original pegmatite constituent at Mount Mica, in Paris, and at a few other localities.

Quartz.—White or gray; one of the principal constituents of all the pegmatites. Massive rose quartz occurs in a few places and crystal groups of amethystine and smoky quartz are developed here and there on the walls of pockets in the pegmatite.

Rhodochrosite.—An original pegmatite constituent at the Towne quarry in Auburn.

Schorl.—See Tourmaline.

Spinel.—Reported from pegmatite at Cobble Hill in Norway.

Spodumene.—Common in many of the coarser pegmatites, especially those that carry gem tourmalines, lepidolite, and other lithium minerals.

Titanite.—A minor original constituent of many of the pegmatites.

Topaz.—An original constituent of a few of the coarser pegmatites. Usually forms crystals on the walls of cavities. A massive constituent of some of the solid pegmatites.

Tourmaline.—Schorl or black tourmaline is a common constituent of many of the pegmatites. Colored tourmalines occur in some, in many places completely inclosed by other minerals, but in others implanted on the walls or lying on the floors of cavities.

Triphylite.—An original pegmatite mineral at Harndon Hill in Stoneham. Associated with spodumene in Peru.

Triplite.—An original constituent of pegmatite in Auburn and Stoneham. Present only in small amounts.

Vesuvianite.—Reported from pegmatite at Mount Rubellite in Hebron.

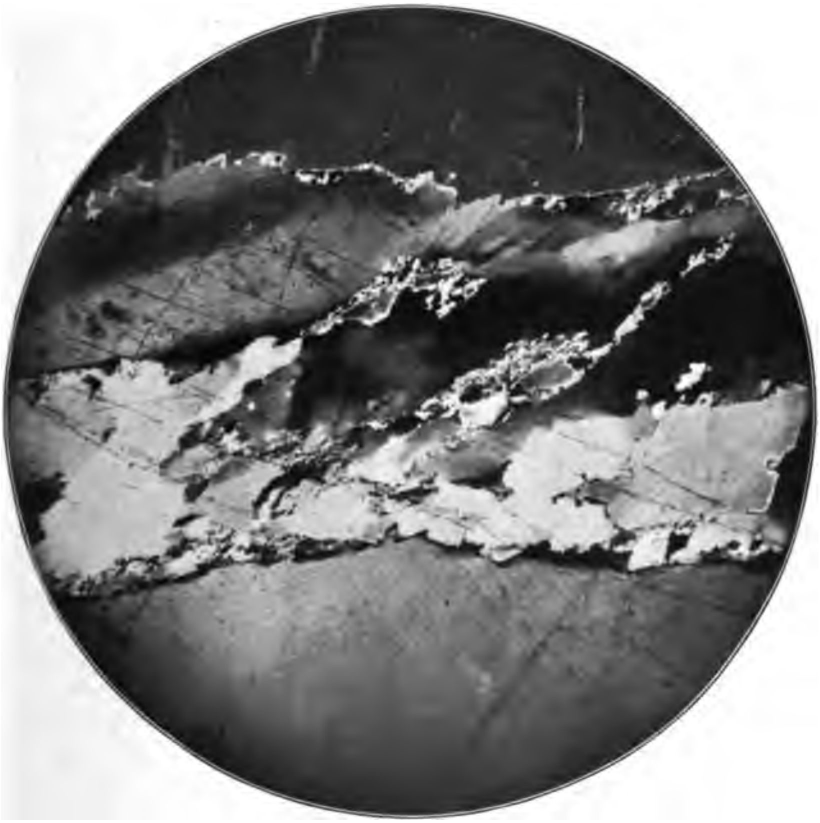
Yttrocerite.—Reported from pegmatite at Mount Mica, in Paris.

Zircon.—Reported from pegmatite in Auburn and Norway and from Mount Mica, in Paris.

Relative proportions of minerals.—Not only are a great variety of minerals present in the pegmatites, but there is also much variability in their relative proportions. In the vast majority of deposits the pegmatite minerals appear to be present in very nearly the same proportions as in the associated granites. Variations in their proportions are principally along two lines, the first involving an increase in silica, the pegmatite becoming more quartzose; and the second involving an increase in both sodium and lithia, the pegmatite becoming rich in albite (variety clevelandite) and in the lithium minerals, lepidolite, spodumene, colored tourmaline, and amblygonite. A minor variation involving an increase in the fluorine content is shown by the presence of the fluorine minerals topaz, fluorite, herderite, hamlinite, certain types of apatite, etc. Increase in soda and lithium and increase in fluorine are both usually accompanied by some increase in the phosphorus content. Cavities which were probably originally filled with water are more abundant in the soda-lithium rich pegmatites than in the normal pegmatites. As shown later, the magmas from which the former solidified were presumably more aqueous than those of the normal pegmatites.

Quartzose phase.—The first type of variation, increase in the quartz content, is not as common a phenomena in Maine as in certain other regions where pegmatites are abundant, and it commonly takes place on a small scale only.[a] Quartzose phases of the pegmatite are particularly well shown on a nearly bare hilltop 2½ miles northeast of Paris in Oxford County, where the pegmatite is cut by a number of quartz veins or dikes mostly under 6 inches wide and mostly parallel to a rather poorly defined system of joints in the pegmatite. Some

[a] Certain large quartz dikes may be genetically connected with the pegmatite magmas. Such connection has not as yet, however, been proved.



ZONE OF STRAIN, FRACTURE, AND RECRYSTALLIZATION IN ROSE QUARTZ FROM NORWAY, MAINE.

Magnified about 34 diameters. Shows the continuance of certain of the straight bands of inclusions from the unstrained quartz into the strained zone.

of these quartz veins possess very sharp boundaries, but others are only vaguely delimited from the pegmatite. The quartz veins of the latter type are particularly likely to contain scattered crystals of orthoclase-microcline and some muscovite and black tourmaline. Black tourmaline is also in some of the veins associated with quartz alone, the two minerals being in many places intimately intergrown. In some narrow veins the black tourmaline may be more abundant than the quartz. In one place the genetic relation between a quartz vein and the pegmatite was shown in the unequivocal manner illustrated in figure 3. Contemporaneous quartz dikes in pegmatite are also well exposed in the Boothbay Harbor region. (See p. 166.)

At a large number of localities, where injection gneisses are associated with pegmatite, quartz stringers in the gneiss can be traced into continuity with the pegmatite. A striking instance of this is illustrated in Plate IV, *B*.

In the Maine deposits quartz is very rarely found in distinct bands in dikes or sills of pegmatite. In a single small dike in Topsham some concentration of quartz in the central portion of the dike was observed, the feldspar being concentrated mainly along the walls.

FIGURE 3.—Quartz offshoot from pegmatite, Paris. Me.

Four thin sections of rose, white, and gray quartz from the larger quartz masses in the pegmatites were examined under the microscope. One of these consisted of a single quartz individual, but the other three showed several interlocking quartz grains within the small area covered by the microscope slide. The quartz in all of these showed little or no strain except along an occasional zone of fracturing and recrystallization such as that shown in Plate VI. In one specimen of quartz from a quartz-rich pegmatite near Cumberland Mills (see p. 62) all of the grains are much strained and are granulated along their borders. Like the development of mica-coated shear planes in certain pegmatites, this indicates slight local shearing movements subsequent to some of the pegmatite crystallization. Such phenomena are the exception, however, and not the rule.

Fluidal cavities.—Fluidal cavities of microscopic dimensions are abundant in most of the pegmatite quartz examined. They are very similar in character in almost all the quartzes, characteristic forms being shown in figure 4. Nearly all contain a vacuole or gas bubble, which in the larger cavities reverses its position in the cavity when the slide is rotated in a vertical plane, moving always slowly toward the top of the cavity and thus indicating that the vacuole is of lower density than the inclosing fluid. An examination of a number of thin sections of Maine granites shows that the inclusions in the quartzes of both pegmatites and granite are similar in character and distribution and are not noticeably different in abundance. In both types of rocks the fluidal cavities are generally arranged in bands, most of which are nearly straight, though some are wavy. Some of these bands terminate abruptly at the border of a quartz grain, but others pass without change or deflection from one quartz grain to another. In the rose quartz illustrated in Plate VI some of the bands of fluid inclusions in the larger quartz grains terminate abruptly at the sheared and recrystallized zone and others continue into it. Bands of inclusions also pass from grain to grain within the sheared zone. It appears therefore that some of the bands of inclusions are not only later than the original crystallization of the quartz but are later even than the straining, granulation, and recrystallization which subsequently affected it.

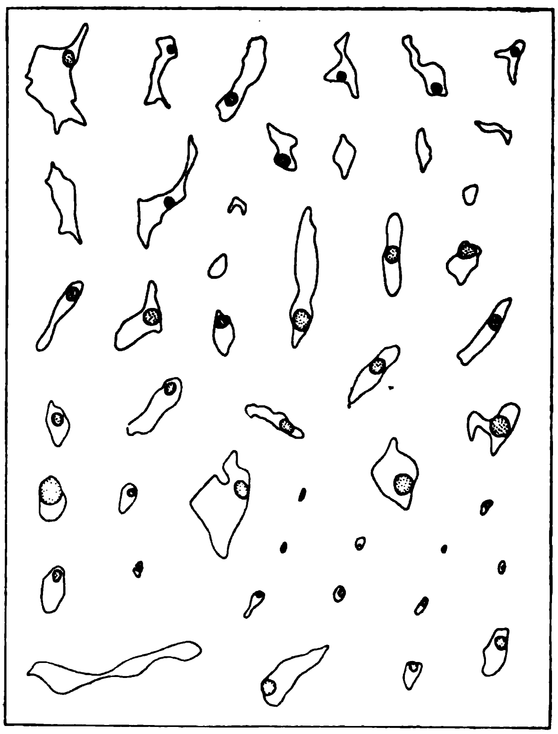


FIGURE 4.—Fluidal cavities in pegmatitic quartz. × 360.

The tint and degree of opacity exhibited by the quartz seems to be dependent in some measure on the abundance and distribution of the inclusions. In several pieces of dirty-gray, opaque quartz, inclusions were particularly abundant and were not confined to bands but were also scattered irregularly through the quartz. A thin section of transparent smoky quartz from the Berry quarry in Poland was seen under the highest available power of the microscope (540 diameters) to be clouded with inclusions so minute that their character could not be made out. They were not arranged in bands and the usual type of fluidal cavities was entirely absent. It is not uncommon for the inclusions in pegmatite quartzes to be in two dominant sets of bands nearly at right angles to each other and showing considerable uniformity of trend throughout the area of the thin section. A thin section of an intergrowth of quartz and garnet from Mount Apatite showed well-developed bands of inclusions in both minerals, though the bands were most abundant and regular in the quartz. The inclusions appeared to be of the same type in both, but none were observed to pass from one mineral to the other. Alternating bands of clear and opaque quartz conspicuous to the unaided eye in the quartz of certain pegmatites are due to the much greater abundance of fluidal cavities in the opaque areas.

Dale[a] reports fluidal cavities ranging from 0.00285 to 0.062 millimeter in Redstone, N. H., granite. Fluid inclusions in the quartz and garnet intergrowth described above ranged from 0.0015 to 0.0068 millimeter. Those in the quartz of fine-grained granite associated with pegmatite at Rumford Falls ranged from 0.0015 to 0.01 millimeter in diameter. In the associated pegmatite from the same locality inclusions similar in character occurred in bands and showed the same range in size. In both of the Rumford Falls rocks the bands of inclusions in the quartz terminate abruptly against bordering feldspars. In the latter mineral no fluidal cavities were observed.

Sodium and lithium phases.—Increase in the proportions of sodium and lithium in the pegmatites results in the formation, in regions where most of the pegmatite is of normal character, of a few bands or zones characterized by the presence of clevelandite, lepidolite, spodumene, and colored tourmalines in addition to the more common pegmatite minerals. The rich tourmaline-bearing pegmatites of Mount Mica and Mount Apatite are of this type. Increase in the phosphorus content is shown by the presence of amblygonite in nearly all such deposits. The sodium and lithium rich pegmatites are confined almost exclusively to the western part of Androscoggin County and to the central and eastern part of Oxford County; practically all occur within a radius of 30 miles from Mount Mica, the richest discovered locality. Although it is true that the pegmatites within this area are richer than the normal pegmatites in sodium and lithium their average composition is but slightly different, since even within this area the sodium and lithium rich phases constitute only a small proportion of the total mass of the pegmatite.

Fluorine phase.—Some sodium and lithium rich pegmatites carry fluorine minerals, but pegmatites carrying fluorine and phosphorus minerals alone in addition to the normal pegmatite constituents are confined largely to the western part of Oxford County. Even there they constitute but a small proportion of the total mass of pegmatite present.

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[a] Dale, T. N., Commercial granites of Massachusetts, New Hampshire, and Rhode Island: Bull U. S. Geol. Survey No. 354, 1908, p. 42.

Muscovite phase.—A few deposits showing local increases in the proportion of muscovite have been worked for this mineral in the past, but have not been commercially successful.

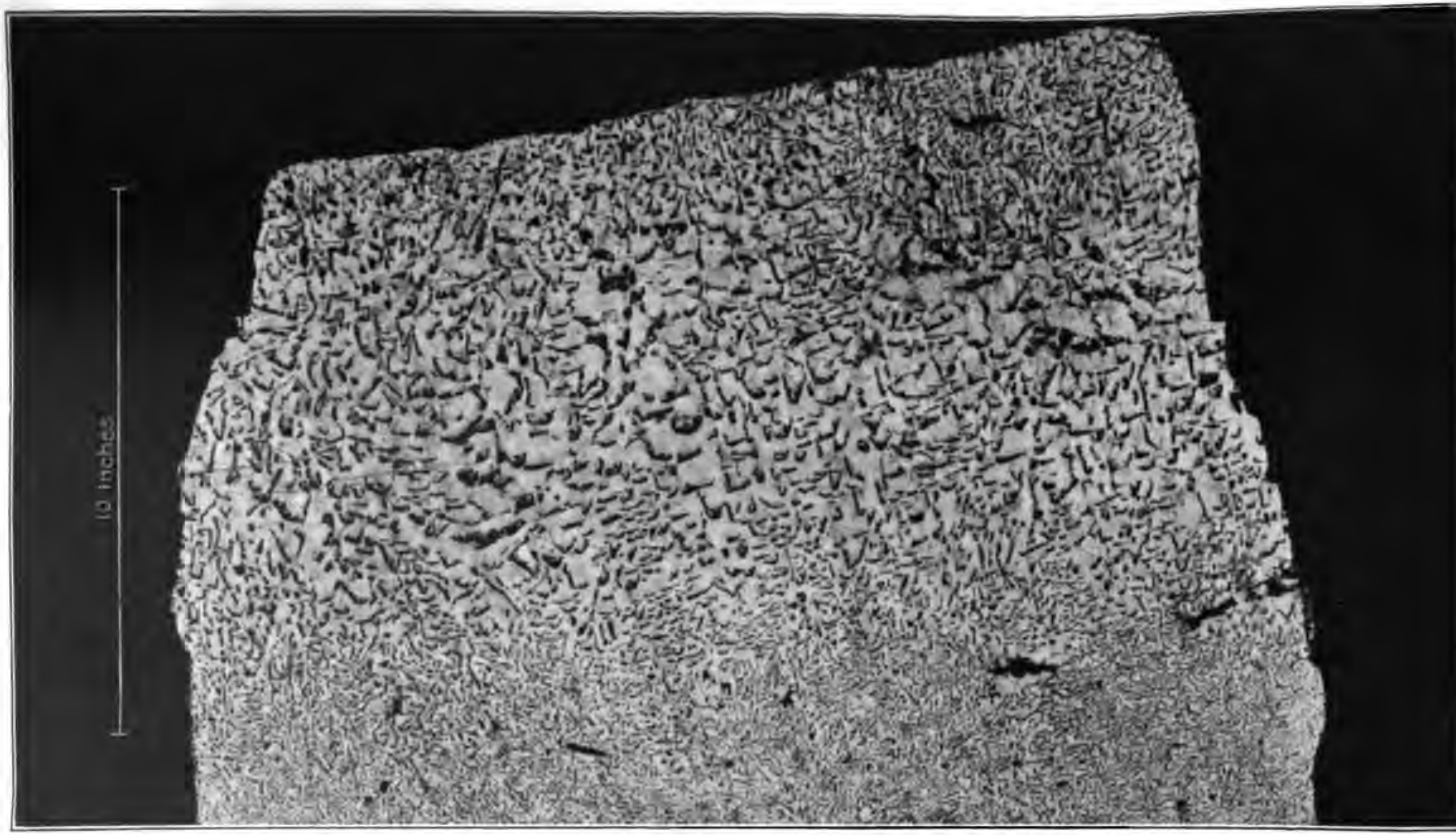
TEXTURE.

The pegmatites show remarkable differences in coarseness, some, especially the narrower dikes and sills, being but little coarser than medium-grained granites, though differing strikingly from the latter in texture, and others containing single crystals of nearly pure feldspar 20 feet across and single beryl crystals the diameter of a hogshead. The majority of the deposits are nearer the lower limit than the higher. Only the coarsest deposits are commercially valuable for their feldspar, quartz, mica, or gem minerals, and these constitute a relatively small percentage of the total mass of pegmatitic material present in any district. In most of the pegmatites worked commercially the feldspar and quartz crystals will not average more than 4 or 5 feet in diameter.

Irregularity of grain.—The most striking characteristic of the texture of the pegmatites, with the exception of the graphic intergrowths described below, is their irregularity. Typical granites show considerable uniformity in the size of grains of the same mineral species, but the pegmatites show no such regularity, a feldspar crystal, for example, being as likely to be two or three or even ten times as large as an adjacent crystal as to be of equivalent size. This feature is shown on a microscopic scale in Plate II.

Graphic granite.—Most of the pegmatites contain much graphic granite, formed by an intimate intergrowth or interpenetration of large single crystals of quartz and feldspar. In certain directions through these intergrowths the quartz forms an angular pattern somewhat resembling the cuneiform inscriptions of the ancients. (See Pl. XVIII.) Fine-grained phases pass in the most gradual manner into coarser graphic granite (Pl. VII); and the latter, by decrease in the percentage of quartz, may pass into masses of pure feldspar, or by decrease in the percentage of feldspar into masses of pure quartz. Much of the material mined as "spar" is coarse-grained graphic granite containing from 10 to 20 per cent of free quartz.

On casual inspection the coarser types of graphic granite appear to contain a somewhat larger proportion of feldspar than the finer-grained types. Chemical analyses of graphic granites of different coarseness from Maine and from other districts indicate, however, that the proportion of feldspar to quartz bears no marked relation to the coarseness. Such variations as do occur are within relatively narrow limits and appear to be dependent on the composition of the feldspar and on other factors not yet understood. Analyses of graphic granites of widely different coarseness from the Fisher



GRAPHIC INTERGROWTH OF MICROCLINE AND QUARTZ OF GRADUALLY VARYING COARSENESS.

Mount Apatite, Auburn. From specimen in U. S. National Museum.

feldspar quarry in Topsham are given on page 124. In the quarry these two rocks graded gradually into one another, and as shown by the analyses the proportion of feldspar to quartz is nearly identical in both. The samples analyzed were obtained by grinding five or six pounds of each granite and quartering down the product to a quantity convenient for analysis. Some allowance must, of course, be made for the difficulty in procuring a sample that is truly representative of the rock mass. This difficulty was greater in the case of the coarser rock.

Feldspar "brushes."—A very uncommon type of graphic granite was observed only in Topsham, in the G. D. Willes feldspar quarry, where it was exposed on the extreme southern wall in dikelike bands in the normal pegmatite up to a foot or so in width. These bands appear to the unaided eye to consist largely of buff-colored feldspar with different though minor amounts of biotite. The feldspar forms an aggregate of brush-shaped or long fan-shaped crystals placed with their long axes at right angles to the general trend of the dikelike band. A faint banding in these layers parallel to their general trend and at right angles to the trend of the feldspar brushes somewhat simulates bedding.

This banding is the combined effect (1) of a greater abundance of biotite along certain layers than along others; (2) of the presence of zones quite even in width, characterized by a coarser intergrowth of feldspar and quartz than the adjacent layers, though generally showing crystallographic continuity from one layer to another and even into a third layer; and (3) of the presence of some parting along planes parallel to the *a* pinacoid and resulting slight clouding of the feldspar by alteration along these fractures.

Single feldspar brushes range in length from a fraction of an inch to 3 inches. The biotite forms thin knife-blade crystals which range in lenght from microscopic dimensions up to three-fourths of an inch and are oriented in about the same direction as the feldspar brushes, penetrating or lying between them.

Under the microscope the brush-shaped crystals are seen to be made up not of feldspar alone but of a graphic intergrowth of quartz and feldspar of microscopic dimensions. The brushlike form represents, however, the form of the feldspar crystal. Quartz having one optical orientation frequently extends from one feldspar crystal into a neighboring one. The microscope shows also that the feldspar is not all of one variety. That forming the brush-shaped crystals is largely microcline, but some plagioclase, mostly in aggregates of irregular grains between the brush-shaped crystals, is associated with it. The plagioclase is albite and is in places graphically intergrown with quartz. Quartz with the same optical orientation in many instances continues from a crystal of microcline into a neighboring one of albite.

The long straight blades of biotite are idiomorphic with respect to the quartz and feldspar grains and their intergrowths. The biotite blades are paralleled in many specimens by an abundance of microscopic blades of muscovite alternating with thin layers of quartz. Other blades of muscovite traverse the rock in the same manner that biotite does, though they are much smaller.

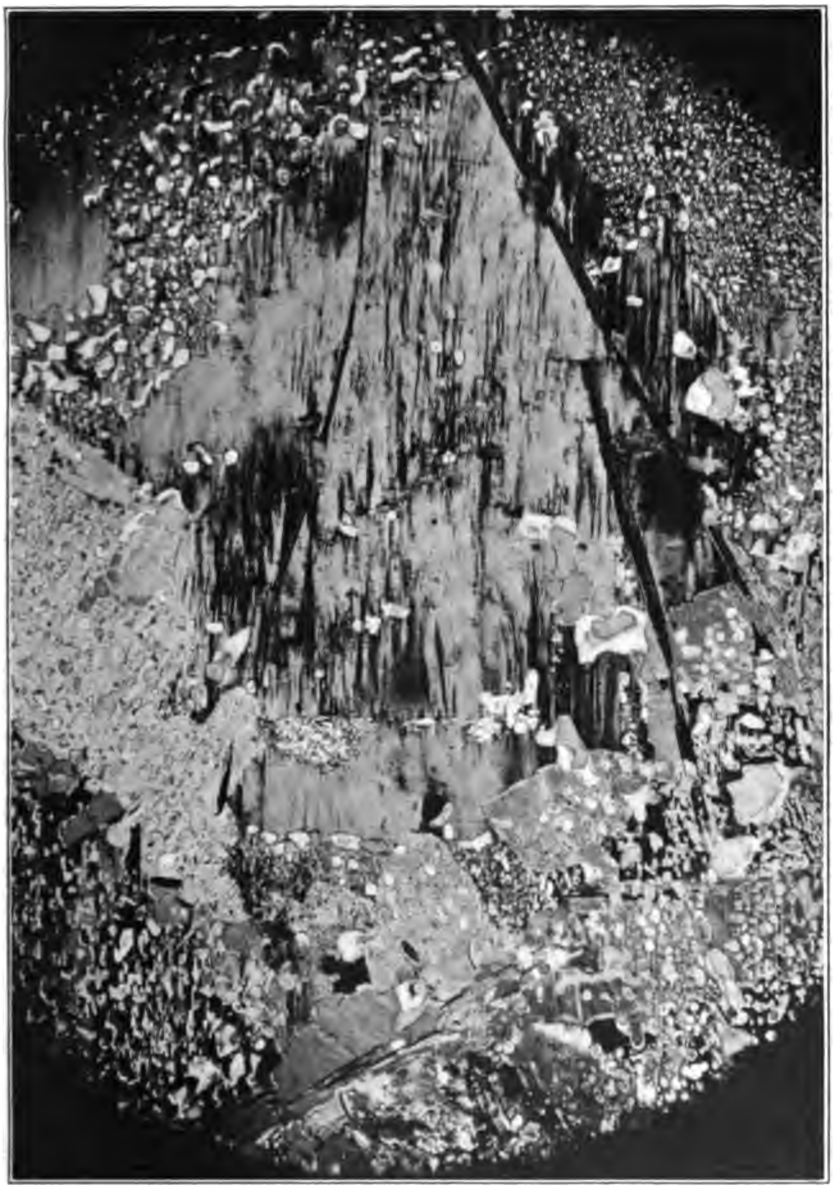
The coarseness of the graphic intergrowth of quartz and feldspar described above varies notably, even where only one quartz and one feldspar individual are involved. There does not appear, however, to be any important difference in the relative proportions of the minerals involved. On the contrary, it is notable that the areas of graphic intergrowth, whether coarse or fine, terminate very abruptly against areas of pure feldspar that are crystallographically continuous with the feldspar of the intergrowth (Pl. VIII) and that show no transition through intergrowths characterized by progressively smaller proportions of quartz. The quartz and feldspar thus appear to be intergrown in rather definite proportions or not at all.[a]

Very little is known of the physical-chemical conditions that produce the peculiar types of crystallization described above. The mode of occurrence in the Alaskan and New Mexican examples suggests, however, that the brush-shaped crystals developed rapidly in a border portion of the magma where the temperature gradient was

[a] Adolph Knopf, of the U. S. Geological Survey, in a personal communication states that he has observed radiating graphic intergrowths identical with those of the Maine specimens in rocks from the Cape Mountain region near Cape Prince of Wales in Alaska. The specimen brought from the field was indistinguishable in appearance from the Maine specimens except that the graphic intergrowth was slightly finer grained. Its mode of occurrence, however, was wholly different. It occurs at the border of sills of microcline-orthoclase-biotite granite which radiate from a central granite massif at their contact with limestones. The latter have been metamorphosed by the granite with the development, within 3 feet of the contact, of numerous contact-metamorphic minerals. The contact zones of micrographic granite range up to 8 inches or so in width, though the individual brush-shaped crystals are not over 4 inches in length. In a microscopic section parallel to the long axis of one of the "brushes" and about parallel to the c (001) pinacoid of one of the feldspar crystals, the cross sections of the quartz bands are for the most part elongate rod-shaped. In some of these the long axis is the direction of fastest light transmission; in others it is the direction of slowest. Single microcline crystals may be intergrown with several quartz crystals, each with slightly different orientation and slightly different trend of their blades, which repeat in miniature the brushlike forms assumed by the microcline crystals. A feature observed in both the Maine and Alaskan specimens is the frequent abrupt termination of the quartzes along planes transverse to the axes of the brushes, other sets of intergrown quartzes beginning with equal abruptness farther on. The microcline is crystallographically continuous across these hiatuses. In other places the fine graphic intergrowths are succeeded abruptly along planes at right angles to the length of the brushes by coarse ones. As in the Maine specimen, grains of albite, usually graphically intergrown with quartz, occur between some of the quartz-microcline "brushes," and between others occurs a granular aggregate of quartz, microcline, and albite. There are occasional short blades of biotite.

Bands of brush-shaped intergrowths of feldspar and quartz, similar in appearance to the Maine and Alaska occurrences but of microscopic dimensions, were also studied in a microscope slide in the collection of the United States Geological Survey. This shows the contact between a coarse quartz diorite and an intrusive aplite dike from New Mexico. For 0.15 millimeter from the diorite contact occurs a granular aggregate of quartz and feldspar so fine that it may represent a devitrified glass; the next zone, 0.60 millimeter in average width, is made up of brush-shaped intergrowths of feldspar and quartz radiating from the finely crystalline zone mentioned above into the main mass of aplite.

Frank C. Calkins, of the United States Geological Survey, reports in a personal communication the occurrence near Anaconda, Mont., of borders 1½ inches or so in width similar to the Alaskan and Maine occurrences in general appearance, at the contact between diorite and an intrusive mass of biotite granite. No specimens of these were collected for study but presumably they are similar in structure to those here described.



PHOTOMICROGRAPH OF GRAPHIC GRANITE FROM TOPSHAM, MAINE.

Magnified about 34 diameters. Note the abrupt termination of areas of graphic intergrowth against areas of pure feldspar, even where the feldspar is crystallographically continuous from one to the other.

steep. In general the brushes are elongate in the direction probably characterized by the most rapid temperature variation, that is, at right angles to the bordering wall. It is possible that progressive differences in concentration of the magmatic solution as the wall rock was approached were also in part the cause of the faster growth of the crystals in that direction. The brush-shaped crystals noted in Maine unquestionably represent a phase of the pegmatite crystallization, evidently one of its later stages.

In addition to the graphic intergrowths of feldspar and quartz the quartz in many of the Maine pegmatites assumes branching or arborescent forms in the feldspar.

Intergrowths of minor constituents.—Graphic intergrowths are not confined to feldspar and quartz but even in the same pegmatite mass may often be found between several of the less abundant constituents. The most common of these are intergrowths of muscovite and quartz in which a single crystal of muscovite is penetrated both parallel to and across its laminæ by quartz. The quartz in some specimens seems to be one crystal, in others, several. The pattern produced on surfaces parallel to the muscovite cleavage resembles that of graphic granite but is somewhat less regular. In some specimens these intergrowths are fine-grained in their centers and become progressively coarser outward, terminating occasionally in blade-shaped crystals of muscovite. In some places the intergrowths are brush or rosette-shaped, and in others the graphic intergrowths form borders about sharply bounded hexagonal crystals of muscovite, the muscovite of the intergrowth being crystallographically continuous with that of the crystal core.

Intergrowths of quartz and garnet are also common and in certain directions through them have a more or less graphic pattern. Some of these intergrowths are 2 to 3 inches across and they commonly possess well-defined crystal faces, their outer portions being almost entirely garnet. When broken open, however, they are seen to be intergrowths of garnet with quartz, the rods and blades of the latter in many places radiating toward the crystal faces. Garnet is locally intergrown with the quartz of the quartz-muscovite intergrowths.

Intergrowths of quartz and black tourmaline are also common, the tourmaline usually radiating from a core composed wholly of tourmaline. At Mount Mica clusters of nearly parallel black tourmaline crystals, mostly from one-eighth to one-half inch in diameter, embedded in a satiny matrix of very minute muscovite flakes are occasionally found. The tourmaline rods of these intergrowths commonly emerge from the end of a large tourmaline crystal.

Intergrowths occur of a character less regular and intimate than those already described. Microcline feldspar is locally intergrown to some extent with muscovite, lying between the mica folia or cutting across them. Many small garnets with well-developed crystal forms are partly or wholly inclosed by muscovite. Lath-shaped crystals of biotite bordered by muscovite are sometimes found, the cleavage planes of the two micas being absolutely coincident. Crystals of tourmaline lying in somewhat flattened form between the plates of a mica crystal are common, and some small, colored specimens are of much delicacy and beauty. At Black Mountain, in Rumford, spodumene was observed intimately intergrown with quartz.

Mica.—In many of the pegmatite bodies muscovite is not evenly distributed throughout the mass but is most abundant in certain zones. (See Pl. IX, *A*.) These zones appear to be distributed through the pegmatite in a totally haphazard manner, bearing no relation to the general form of the pegmatite mass nor to the position of the wall rocks. The central portions of these muscovite belts for a width of a few inches consist of an aggregate of heterogeneously arranged muscovite plates, few of them more than one-fourth inch in diameter. (The hammer head in the illustration, Pl. IX, *A*, rests on one of these central fine-grained portions.) They are commonly plane or only gently undulating throughout their length and, being lines of weakness, are usually marked by a fracture plane. From this fine-grained portion spearhead-shaped books of muscovite, showing wedge structure (see p. 139), project in a direction nearly at right angles to the general plane of the mica belt; some of these muscovite books are a foot in length. This peculiar distribution of muscovite is not readily explainable; but it seems to represent a muscovite crystallization proceeding not from a single center, but from a plane or from a large number of centers lying in nearly the same plane. In the pegmatite of the Black Mountain mica mine in Rumford, where the mica locally constitutes three-fourths of the pegmatite mass, the elongate mica books near the schist wall rock tend to orient themselves with their long axes perpendicular to the contact. In a number of quarries muscovite crystallization about a center is exemplified by the presence of nearly equidimensional aggregates, some of them 5 feet across, consisting of small heterogeneously arranged plates averaging about one-fourth inch in diameter. From their peripheries these muscovite aggregates send off spearhead-shaped muscovite books into the surrounding pegmatite.

Biotite may occur in isolated lath-shaped crystals penetrating the pegmatite in all directions or in radiating aggregates of such crystals.

Gem-bearing pegmatites.—Pegmatites particularly rich in gem minerals exhibit peculiarities of structure not present in the normal rock. Lithium minerals, such as colored tourmalines, lepidolite, spodumene, etc., and the soda feldspar clevelandite, are concentrated in a zone which usually parallels the plane of greatest dimension of the

A. MUSCOVITE-RICH ZONES IN PEGMATITE. G. D. WILLES FELDSPAR QUARRY, TOPSHAM.

B. POCKET, ABOUT 3 FEET IN DIAMETER, IN GEM-BEARING LAYER AT MOUNT MICA. OPENED JUNE, 1904.

The giant compound tourmaline crystal shown in Plate XIV came from this pocket; also another similar but smaller compound tourmaline crystal; two large simple tourmaline crystals, one of which is shown in Plate XV; about $1,300 worth of red and pink gem tourmalines; and about $300 worth of green gem tourmalines. In all the pocket yielded about 75 pounds of tourmaline. Photograph by Mr. A. A. Norton, of Portland, Maine.

commonly lens-shaped pegmatite body. Within this zone pockets are also apt to be particularly abundant. Pockets are found in some of the normal pegmatites also, but their disposition seems to be wholly sporadic and most of them are barren of gem minerals, though some contain groups of fine quartz crystals or of small feldspar crystals on their walls.

In the richly gem-bearing pegmatites the zone of sodium and lithium minerals is generally separated from the normal pegmatite which borders it by a highly garnetiferous zone from an inch to several inches wide, the garnet being associated with a granular aggregate of quartz and feldspar. A few such bands are paralleled by a second one of similar character 1 or 2 inches away. These garnet bands are frequently of practical service in tracing the gem-bearing zone. The pegmatite outside them is invariably barren of gem minerals.

As explained in the detailed descriptions of Mount Mica and other gem localities, the gem tourmalines are usually found in pockets, having developed on their walls. The pockets, though confined mainly to the zone rich in soda and lithium minerals, may be wholly absent from considerable portions of such zones and are distributed with great irregularity through the remaining portions. The character and distribution of pockets is best illustrated at the Mount Mica tourmaline mine. Plate XII is from an early photograph of the workings at Mount Mica, taken at a time when only the outcropping portion of the gem-bearing zone had been worked. A stake with card attached marks the position of each pocket.

Most of the pockets are somewhat spherical in form, but others are oval or elongate and others exceedingly irregular. Their size ranges from a few inches across to a magnitude such as is shown in Plate XIII, which represents the largest pocket ever found at Mount Mica.

Minor details of structure of the gem-bearing pegmatites are discussed in the locality descriptions (p. 18).

ORIGIN OF THE MAINE PEGMATITES.

The writer does not purpose in this report to discuss the voluminous literature on pegmatites except in so far as it bears closely on those of the region under discussion. Previous writings and theories have been well summarized by George H. Williams[a] and especially by Brögger.[b]

RELATIONS TO GRANITES.

The geologic relations of the Maine pegmatites, as already pointed out (pp. 13–15), show beyond reasonable doubt that they are geneti-

[a] Williams, G. H., Fifteenth Ann. Rept. U. S. Geol. Survey, 1895, pp. 675–684.

[b] Brögger, W. C., Der Syenitpegmatit-gänge der sudnorwegischen Augit und Nephelinsyenite: Zeitschr. f. Kryst., vol. 16, 1890. Sections on genesis translated in Canadian Rec. Sci., vol. 6, 1894, pp. 33–46, 61–71.

cally connected in a most intimate manner with the granites. Evidence of this is found in mineralogical similarity, in the invariable presence of granite in all areas where pegmatite is found, and in many actually observed transitions from one to the other. (See fig. 2.)

If we admit a genetic connection between the pegmatites and granites, it is next of importance to inquire what evidence is afforded by the Maine pegmatites as to the physical and chemical conditions which resulted in the crystallization from related magmas of rocks of such widely varying character.

EXTERNAL CONDITIONS.

Differences in external conditions at the time of crystallization appear inadequate to explain the observed textural differences. This is shown by the close association of the two types of rocks—an association already cited as evidence of their genetic relationships. The field relations show that in many instances the external conditions, such as the nature and temperature of the wall rock, the depth at which solidification took place, etc., were similar for both types of rocks. In cases such as that shown in figure 2 the general external conditions must have been practically identical. A similar conclusion is justified in numerous other instances where granite and pegmatite grade into each other, and especially where pegmatite forms segregation-like masses wholly inclosed in granite. Conversely, the broad, general similarity of the pegmatites over very large areas where the external conditions were certainly not constant also indicates that the causes of their peculiar textures were in the main internal rather than external. It seems necessary to look, therefore, to differences inherent in the magmas themselves for an explanation.

DOMINANT CONSTITUENTS.

The characters shown by the Maine pegmatites accord with the evidence obtained from many other districts in indicating (1) that the pegmatite magmas were characterized as a general rule by the presence of certain components in amounts larger than occur in normal granite magmas, and (2) that to these differences in composition were in large measure due the differences in texture. The exact nature of such differences is, however, more largely a matter of inference than of direct field observation.

In the great mass of the normal pegmatite it is exceedingly difficult, if not impracticable, to make a satisfactory estimate of the relative proportions of the different mineral constituents. So far as can be judged without measurements the proportions are of the same general order as in the normal granites, except that the pegmatites are probably on the average slightly more quartzose, a conclusion that seems warranted by the numerous transitions from pegmatite masses into veins composed largely or wholly of quartz. The differences in the proportions of the principal mineral constituents in the normal granites and the normal pegmatites seem, however, insufficient to account for the great differences in their textures. It appears necessary to seek the cause of these contrasts in differences in the proportions of minor constituents or in the presence in the granite or pegmatite magmas of constituents which have since escaped or which, through occlusion, are not now visible to the unaided eye in the derived rocks.

MINOR CONSTITUENTS.

The presence in many pegmatites of unusual minerals, such as fluorite and other fluorine-bearing minerals, lithium minerals, boron and phosphorus minerals, and occasionally rare earth minerals, has led certain geologists[a] to attribute to some of these substances an important rôle in the production of pegmatite textures. It can not be doubted that when present in magmas such substances have some influence upon the texture of the resulting rock. It has not been demonstrated, however, that the presence of these unusual constituents is essential to the development of typical pegmatitic textures. In the opinion of the writer their presence is probably not essential. The pegmatites which earliest attracted the attention of American mineralogists and geologists, and which have been most often described in the literature, were naturally those in which unusual minerals were present in especial abundance or in perfection of crystal form. Such pegmatites constitute, however, only an exceedingly small proportion of the pegmatite in any district and must be regarded as unusual rather than as normal types. The writer is familiar with certain deposits showing typical pegmatitic textures, which have been worked for their feldspar for years with the discovery of few if any of the rarer minerals.[b] In by far the greater number of the pegmatites of Maine unusual minerals are so uncommon as ordinarily to escape detection. In pegmatites in which they are present their paucity or abundance seems to have small influence on the textures developed. Those inclined to attribute large influence in the development of pegmatitic textures to the presence of rare constituents usually contend that a more careful study will show that their scarcity is more apparent than real. Such an assumption is not in

[a] Certain French geologists in particular have supported this view. See De Lapparent, Traité de géologie, 4th ed., 1900, p. 630; De Launay, La science géologique, 1905, pp. 557-558, 582-583.

[b] The Andrews feldspar quarry in Portland, Conn., the Mitchell feldspar quarry in Maryland, and the Goldings feldspar quarry in Georgetown, Me., are examples. See Bull. U. S. Geol. Survey No. 420, pp. 50, 75, and this report, p. 105.

accord with the field observations of the writer in Maine and other parts of New England, and it appears to be unwarranted.

GASEOUS CONSTITUENTS.

If neither the dominant nor the rare minerals of the pegmatites have been controlling factors in the development of typical pegmatitic textures, it appears necessary to seek an explanation in the presence in the magmas of certain constituents which have subsequently escaped or at least are not readily recognizable in the resultant rock. The fact that large crystals can not be obtained at atmospheric pressures from simple dry melts of the commoner rock-forming minerals suggests at once that the crystallization of these minerals in nature took place either under widely different physical conditions (such as high pressure) or in the presence of certain substances which are scarce or absent in the rocks as now exposed. It has already been argued from field evidence (p. 28) that in many instances differences in pressure or other external conditions at the time of crystallization can not reasonably be adduced to explain the textural variations observed. In such cases an appeal to the escaped constituents of the magma appears unavoidable. The same conclusion appears necessary when the extreme viscosity exhibited (under atmospheric pressures) by silica, orthoclase, and albite near the melting temperatures is considered. The various forms of silica that have been artificially produced have all crystallized from a melt so viscous as to be virtually a glass.[a] As regards orthoclase the viscosity of its melt is so great that all attempts to crystallize the mineral from it have been unsuccessful. Since increase in pressure can hardly be appealed to as increasing molecular mobility[b] in magmas, it seems necessary again, in accounting for the large crystals developed in the pegmatites, to postulate the presence in the magma of some substance or substances not now recognizable in the derived rock. That the presence of volatile constituents in a magma does influence the viscosity is shown by the fact that certain obsidians may be readily melted with evident fluidity and the escape of gases, but that their refusion after such gases have escaped is much more difficult. Iddings[c] has also shown from a microscopic study of the obsidian of Obsidian Cliff, Yellowstone National Park, that where there was more dissolved gas the conditions were more favorable for crystallization than in other parts of the magma.

Among those constituents of magmas which might escape, leaving little record of their former presence, water gas and hydrogen are

[a] Day, D. T., and Shepherd, E. S., The lime-silica series of minerals: Am. Jour. Sci., 4th ser., vol. 22, 1906, pp. 271-273. Day, D. T., and Allen, E. T., The isomorphism and thermal properties of the feldspars: Pubs. Carnegie Inst., No. 31, 1905, pp. 28-29 and 45-55.

[b] Harker, Alfred, The natural history of igneous rocks, 1909, pp. 163-164.

[c] Iddings, J. P., Seventh Ann. Rept. U. S. Geol. Survey, 1888, pp. 283-287. Also Igneous rocks, 1909, p. 185.

probably the most abundant, as is plainly indicated by analyses of the gases still remaining in igneous rocks[a] and by studies of the gases emitted from volcanic vents.[b]

The presence of water gas in association with subordinate amounts of other gases and of certain unusual substances (mineralizers) has been considered by many observers to be the competent and effective cause in the development of pegmatitic textures. With this opinion the present writer is in general accord, though the persuasion is based more largely on the process of reasoning already outlined than on field evidence of high-water content or relatively low viscosity in pegmatite magmas. The field evidence gathered in the study of the Maine pegmatites is summarized later (p. 45), but must be looked on as merely suggestive; anything like a complete solution of the problem will in all probability wait upon synthetic laboratory experiments on the interaction between gases and rock-forming silicates.

The small weight of the gaseous and liquid constituents of most igneous rocks as compared with the total weight of the rock might lead one to question their competence to notably affect the viscosity of magmas and to produce large textural variations. In this connection it may not be out of place to call attention to a possible application of Raoult's law,[c] according to which if various substances are dissolved in equal amounts of the same solvent in the proportions of their molecular weights the resulting lowering of the freezing point of the solution will be the same in each case.[d] In other words, the effect produced is a function of the number of molecules concerned and is not primarily dependent on the nature of the substances introduced. It follows that a small amount by weight of a substance of low molecular weight (such as H_2O, molecular weight 18) will exert the same depressing influence on the freezing point of the solution as a much greater weight of a substance of high molecular weight (such as Fe_2O_3, molecular weight 160); and that given equal weights of the two the substance of lower molecular weight will exercise much the greater influence. This law has been found to apply strictly only to very dilute solutions where there is no chemical action between solvent and dissolved substance. It has been applied by Vogt[e] to rock magmas, but the wisdom of such extension to cover widely different and much more complex physical conditions may well be questioned. It seems not unreasonable, however, to attribute some general importance to this principle in rock magmas, to the extent that magmatic constituents of low molecular weight may exert

[a] Chamberlin, R. T., The gases in rocks: Pubs. Carnegie Inst. No. 106, 1908. This includes a summary of earlier investigations.

[b] For a review of the literature on volcanic gases, see Clarke, F. W., The data of geochemistry: Bull. U. S. Geol. Survey No. 330, 1908, pp. 212-236.

[c] Ostwald, Wilhelm, Outlines of general chemistry, 1895, pp. 136-137.

[d] Neglecting electrolytic dissociation, which is probably of small importance in rock magmas.

[e] Vogt, J. H. L., Die Silikatschmelzlösungen, vol. 2, 1904, pp. 128-135.

greater influence in lowering the freezing point, decreasing viscosity, and affecting textures, than do constituents of high molecular weight. They may thus attain an importance which appears disproportionate to the small part by weight which they form of the whole magma. The substances (hydrogen, water, fluorine, chlorine, and boron) commonly believed to exert the greatest influence upon the viscosity of magmas and the textures of the resulting rocks are all substances of much lower molecular weights than silica and the rock-making silicates and oxides, even if minimum values for the latter are assumed. The hiatus between the molecular weights of these two groups of substances is so marked as to justify the retention of the term "mineralizers" for the lighter group, in case the principle outlined above is eventually shown to be operative to an important degree in magmas.

VISCOSITY AND GAS CONTENT.

The field and laboratory data on the pegmatites of Maine that bear on the viscosity and gaseous content of the pegmatite magmas may be set forth as follows. As the pegmatite magmas crystallized at some distance below the surface, the gases which they contained must either have made their escape through the wall rocks or else must have remained in cavities or occluded within the solid pegmatite mass. The escape of such materials through the wall rocks should presumably leave some record in contact-metamorphic effects. Their retention within the rock should presumably be recorded in an especial abundance of miarolitic cavities and fluid or gaseous inclusions.

Miarolitic cavities.—The field studies of the writer in Maine and other parts of New England show that the granites are almost wholly devoid of miarolitic cavities of any kind. An isolated cavity of small size is occasionally found, but its walls are usually more or or less pegmatitic in texture. In the great bulk of the pegmatites of Maine, particularly the finer-grained ones, such cavities are also exceedingly rare. In the coarser pegmatites, however, they are a characteristic feature, though usually as far as can be judged constituting considerably less than 1 per cent of the total volume of the pegmatite. Within the very narrow gem-bearing zones of certain pegmatites miarolitic cavities may form a considerably larger percentage of the total volume. Such cavities have been attributed by various writers to shrinkage of the pegmatite mass in crystallization. This may in fact play some part in their formation, but that they are not entirely the result of shrinkage, but, on the contrary, were filled or partly filled with some material which has since disappeared, is shown by the presence of perfectly developed crystals of quartz, tourmaline, and other minerals projecting inward from the walls of the cavities. Some filling must have been present from which such crystals derived the materials for their growth. It is probable, therefore, that immediately after the crystallization of the main body of pegmatite the miarolitic cavities were completely filled with a gaseous solution, which may later have liquified and has since disappeared. Water carrying numerous other substances in solution probably formed the bulk of this cavity filling. The abundance of quartz crystals on the walls of these cavities indicates that silica was one of the most abundant of the dissolved substances.

If the crystallization of the rock with pegmatitic rather than granitic texture is due to the presence of larger amounts of gaseous constituents, greater size or abundance of microscopic fluidal or gaseous cavities might reasonably be expected in the pegmatite minerals than in those of the normal granites. With this idea in mind the writer attempted a microscopic measurement of these inclusions in pegmatites and associated granites from Maine. On account of the uneven distribution of the inclusions in bands traversing the minerals accurate estimates were found to be impracticable and the results were negative or inconclusive. It was found, moreover, that some of the bands of fluidal cavities in the quartz of pegmatite were formed later than shearing movements which had affected the quartz. (See Pl. VI.) The inclusions in the pegmatite were similar in character to those in the normal granites of the State and any differences in their size and abundance in the two types of rocks was not sufficient to be noted on casual inspection.

Contact-metamorphic effects.—If the pegmatite magmas are characterized by considerably larger proportions of gaseous constituents than are present in the granite magmas and hence by notably greater fluidity, notable differences might be expected in the contact-metamorphic effects produced by the two types of rocks, since such effects are believed to be produced largely by gaseous and fluid emanations from the cooling igneous masses. Field observations in Maine fail to show that contact-metamorphic effects due to the intrusions of pegmatite are notably greater than those produced by the granites. The effects produced by both are usually slight and in many instances almost nil. In many places masses both of pegmatite and granite cut across the foliation of schists without any distortion of the latter, the contacts being of knife-edge sharpness. In other places, however, pegmatite has produced a notable softening of the bordering rock, though this effect is usually apparent only close to the contact.

A striking instance of this effect was observed about 2½ miles northeast of Paris village, where a pegmatite mass 2 to 3 feet across and several smaller masses are intrusive in schists of probable metamorphic-sedimentary origin. (See Pl. X, *A*.) Although the schist folia do not in general conform to the outline of the large pegmatite mass, as they would if any considerable amount of softening had occurred, still in a zone an inch or two wide along the immediate contact such softening has taken place with a deflection of schist folia toward parallelism with the pegmatite contact. The bending of the schist folia in the manner shown indicates also that the pegmatite when intruded behaved to a certain extent like a solid body capable of exerting differential thrust on the inclosing walls of schist. In a body behaving essentially like a liquid, pressure would be equalized in all directions and it is difficult to see how such bending of folia along the borders of the mass could occur.

Another instance of still more extensive softening of the schists bordering pegmatite, with the development therein of minerals derived from the pegmatite magma, was observed at Rumford Falls (Pl. X, *B*). The contact is very irregular and the schist folia near the contact curve around so as to conform rather closely to the outline of the pegmatite mass. Not only are there irregular protuberances of the pegmatite into the schist, but there are developed in the schist next to the contact a number of masses, mostly composed of feldspar but with some admixture of quartz, which in the plane of the section are not connected with the main pegmatite mass. There may, of course, have been some connection between them and the main pegmatite body, either above or below the plane of the present surface of exposure. A feature of especial interest is the development in some of these masses of well-defined crystal faces, as is clearly shown in Plate X, *B*, especially in the mass to which the hammer handle points. The straight faces on these masses are parallel to the cleavage directions in the feldspar and there can be no doubt that they are crystal faces. These relations plainly indicate a considerable permeation of the schist by the pegmatite magma and a sufficient yielding on the part of the schist to permit the development of very perfect crystal faces in the feldspar. This may have been accomplished through absorption or by metasomatic replacement of the schist, but other evidence of absorption is wholly absent, for the contacts though very irregular are very sharp, and no difference is noticeable between the pegmatite next the contact and that some distance away. It seems more probable, therefore, that the phenomena observed indicate a yielding of the schist through recrystallization to the pressures of various kinds exerted by the pegmatite.

Further instances of the softening of the schists as a result of the intrusion of pegmatite are exemplified by numerous occurrences of the type illustrated diagrammatically in figure 1 (p. 11), where the schist laminæ show a thickening opposite the nodes of the pegmatite dike or sill and become thinner opposite the bulges.

A. DEFLECTION OF SCHIST FOLIA ALONG THE IMMEDIATE CONTACT WITH A PEGMATITE DIKE.

Two and one-half miles northeast of Paris village, Oxford County.

B. DEVELOPMENT OF FELDSPAR CRYSTALS IN SCHIST NEAR PEGMATITE, RUMFORD FALLS.

Such softening effects as those cited are confined, however, to the immediate vicinity of the pegmatite, usually to a zone a few inches in width, and are the exception rather than the rule, most pegmatite contacts being exceedingly sharp and free from all evidence of softening. Absorption (except in a few doubtful instances) appears to be wholly absent, the contacts even in the places where softening is shown being sharp, and the pegmatite next the contact showing no difference in composition from that at some distance away. Where schist fragments are inclosed in the pegmatite their sharp outlines are preserved. Contact-metamorphic effects of the pegmatite on schists are particularly noticeable at Black Mountain in Rumford. (See p. 96.)

Forms of the intrusives.—If the physical conditions of the pegmatite and granite magmas were notably different at the time of their intrusion, it would be natural to expect some differences in the forms assumed by the granite and pegmatite masses. Though in many cases those forms are similar, there is in general a tendency for the smaller pegmatite intrusions in the foliates to assume the form of a succession of lenses (fig. 1, p. 11) and for the granite intrusions of similar size to be more nearly parallel walled. This contrast is particularly noticeable in the Boothbay Harbor region and near Rumford Falls and is probably expressive of slightly greater rigidity in the granite than in the pegmatite magma and also of greater softening of the inclosing schist by the pegmatite than by the granite magmas. The great size of certain pegmatite masses, such as Streaked Mountain in Hebron, is, on the other hand, suggestive of degrees of viscosity in some pegmatite magmas not widely different from those prevailing in normal granite magmas. The crest of Streaked Mountain was examined for more than half a mile of its length and the width of outcrop examined across the trend of the ridge for about half a mile. The whole area traversed and the remainder of the mountain as far as it could be seen was underlain almost exclusively by coarse pegmatite, the mountain being a "boss" of this material. The pegmatite is of the usual granitic type and exhibits no more than the usual amount of variation in texture and composition from point to point. It is difficult to conceive of a mass of this size and general uniformity crystallizing under anything like vein conditions. With very high gaseous content and correspondingly high mobility it would be natural to expect more differentiation both in texture and composition. It seems probable that the viscosity of such a pegmatite magma was not so much below that of a granite mass intruded under similar conditions as has been commonly supposed.

Fragments of the wall rock are very frequently found inclosed by the border portions of the granite masses of Maine. The phenomenon is much less common in the case of the pegmatites but was nevertheless observed at several localities. On the highest portion of Streaked Mountain a number of patches of schist a few square yards in area were seen apparently entirely inclosed by pegmatite. Small schist fragments are also inclosed by pegmatite in the Boothbay Harbor region. W. H. Emmons, of the United States Geological Survey, who visited Mount Mica a year later than the writer, when the excavation had proceeded farther, observed, a few feet below the schist hanging wall, schist fragments which appeared to be wholly inclosed in the pegmatite. The schistosity of these fragments made large angles with the schistosity of the walls from which they had evidently been dislodged. The pegmatite shows no bending of the minerals nor other changes in character near the fragments. In the instances cited the schist fragments appear to have been caught up while the pegmatite mass was still partly or wholly fluid, and the density of the magma was sufficient, at least in the Mount Mica example, to float the fragments.

TEMPERATURES OF PEGMATITE CRYSTALLIZATION.

Experiments of Wright and Larsen.—Some evidence in regard to the temperatures of the pegmatites at the time they crystallized has been obtained from studies of quartz by Wright and Larsen, some of the specimens being collected by the writer from the pegmatites of Maine and other parts of New England. To quote from their paper—[a]

> For * * * geologic thermometric purposes, quartz has been found by experience to be well adapted. It is plentiful in nature and occurs in many different kinds of rocks. SiO_2 in the form of tridymite melts at about 1,625° (centigrade); between that temperature and about 800° tridymite is the stable phase; below about 800° quartz is the stable phase. From evidence thus far gathered it is probable that pressure has but slight effect on raising or lowering such an inversion point, and that, therefore, whenever quartz appears in nature, it was formed at a temperature below 800°.

The studies of Wright and Larsen and of earlier observers have shown that at about 575° C. there is a sudden change from one form of crystal symmetry to another. Quartz developed below 575° crystallizes in what has been called the α form (the trapezohedral-tetartohedral division of the hexagonal system) and quartz developed above 575° appears to crystallize in the β form (the trapezohedral-hemihedral division of the same system).

> Quartz itself undergoes a reversible change at about 575°. * * * Practically the only crystallographic change which takes place on the inversion is a molecular rearrangement, such that the common divalent axes of the high temperature β form become polar in the α form, and this fact involves certain consequences which can be used to distinguish quartz which has been formed above 575° from quartz which has never reached that temperature. At ordinary temperatures all quartz is α quartz, but if at any time in its history a particular piece of quartz has passed the inversion

[a] Wright, F. E., and Larsen, E. S., Quartz as a geologic thermometer: Am. Jour. Sci., 4th ser., vol. 28, 1909, p. 423.

point and been heated above 575°, it bears ever afterwards marks potentially present which on proper treatment can be made to appear just as an exposed photographic plate can be distinguished at once from an unexposed plate on immersion in a proper developer, although before development both plates may be identical in appearance.[a]

In addition to the change in crystal form at 575°, the quartz exhibits changes in its coefficients of expansion, in circular polarization, and in birefringence.

Briefly stated, the four criteria which can be used to distinguish, at ordinary temperatures, quartz which was formed above 575° from quartz which has never been heated to that temperature, are: (1) Crystal form, if crystals be available, the presence of trigonal trapezohedrons and other evidence of tetartohedrism, irregular development of the rhombs and the like, being indicative of the α form. (2) Character of twinning, as shown by etch figures on the basal pinacoid. In the α form, which crystallized from solutions at comparatively low temperatures, the twinning is usually regular and sharply marked, while in quartz plates originally of the β form and now α by virtue of inversion in the solid state, the lines are usually irregular, and the twinning patches are small and bear no relation to the outer form of the crystal. (3) Intergrowths of right and left handed quartzes are more frequent and more regular in boundary lines in the α than in the β form. (4) Plates of originally β quartz but now α quartz by inversion show the effect of the inversion by the shattering, which should be most evident on large plates. Into all these criteria an element of probability enters, and in testing quartz plates, with this end in view, a number of plates should be examined to strengthen the validity of the inferences drawn.[b]

The bearing of the experiments on the temperatures of crystallization of granites and pegmatites has been briefly discussed by Wright and Larsen, but the writer desires to amplify the discussion by a more detailed description of its relation to those specimens with which he is personally familiar.

No granites from Maine were tested by Wright and Larsen, but thirteen specimens of granites, granite gneisses, and porphyries which were tested from other regions show as a rule the characters of β or high-temperature quartz, thus placing their temperature of final solidification above 575° C.

Two specimens of rose quartz from Maine (Nos. 13 and 14, Wright and Larsen), one of them from Paris, Oxford County, now in the collection of the United States National Museum, were examined by Wright and Larsen and found to show the characters of α or low-temperature quartz. The specimens have the appearance of typical pegmatite quartz; and in Maine rose quartz, so far as known, occurs only as a pegmatite constituent.

A specimen of rose quartz (No. 12, W. and L.) collected by the writer from the feldspar and quartz quarry of P. H. Kinkle's Sons at Bedford, N. Y., also showed the characteristics of α or low-

[a] Wright, F. E., and Larsen, E. S., Quartz as a geologic thermometer: Am. Jour. Sci., 4th ser., vol. 28, pp. 423, 425.
[b] Idem, p. 438.

temperature quartz. This pegmatite has been described by the writer in another report [a] and is similar in most of its characteristics to the coarser Maine deposits. The quartz of this quarry is mostly white but is rose colored in places. It is associated with the feldspar in a wholly irregular manner and forms large masses in one pit, being the principal rock on two of the walls. These quartz masses at their borders are in intimate interpenetration with the feldspar and may even grade into the quartz of graphic granite. There is not the slightest doubt that they form an integral part of the pegmatite mass, though very likely they were the latest portion to crystallize.

Another specimen of quartz, collected by the writer from the pegmatite at an old feldspar quarry on the northwest side of Mount Ararat in Topsham, showed a quartz crystal about 1½ inches across projecting with perfectly developed pyramid faces into a crystal of pink microcline. The crystal faces of the quartz were only shown when the feldspar was broken away. The two minerals formed intimate parts of a large mass of coarse pegmatite and plainly crystallized contemporaneously. The tests on this quartz (No. 20, W. and L.) indicate that it crystallized below 575°.

Another test (No. 18, W. and L.) was made upon quartz collected from the Berry feldspar quarry in Poland, Me. The deposit is a gem-bearing pegmatite and the quartz tested was irregularly intergrown with rounded lepidolite and bladed albite of the clevelandite variety. It occurred in the solid pegmatite but near miarolitic cavities. The tests, though not wholly conclusive, show that it probably belongs to the low-temperature variety.

Crystals of transparent smoky quartz (No. 15, W. and L.) developed on the walls of pockets in the pegmatite at the same quarry exhibited low-temperature characters. Similar results (No. 19, W. and L.) were obtained for a compound quartz crystal developed in one of the pockets at the G. D. Willes feldspar quarry in Topsham. At its proximate end this crystal mass was intergrown with the feldspar of the wall of the pocket. It was plainly a pegmatite crystallization, though a late one.

A specimen (No. 16, W. and L.), taken by the writer from a large mass of white quartz several feet across in the pegmatite at the Fisher feldspar quarry in Topsham, also showed the characters of the α or low-temperature variety. These quartz areas form an intimate part of the pegmatite mass, interlocking at their borders with crystals of the other constituents and in places grading without break into the quartz of coarse graphic granite.

In contrast to the above tests on specimens of quartz from the large quartz masses in the pegmatites and from the quartz in or near

[a] Bastin, E. S., Feldspar and quartz deposits of southeastern New York: Bull. U. S. Geol. Survey No. 315, 1907, pp. 395-398.

the cavities, tests of smaller masses of quartz in finer-grained pegmatite or intergrown with feldspar in graphic granite show that in these crystallization took place above the inversion point of 575° C. Quartz, for example, from a pegmatite dike 1 to 4 feet in width, cutting fine-grained biotite granite in a railroad cut near Rumford Falls (No. 22, W. and L.), proved to be of the β or high-temperature variety. The rock, in addition to quartz, contained microcline and biotite, few of the feldspars exceeding 2 inches in diameter. This dike in texture and coarseness is typical of very many of the smaller pegmatite bodies of the State. Similar results were obtained with quartz (No. 25, W. and L.) from the coarse graphic granite of Fisher's feldspar quarry in Topsham (see Pl. XVIII, and an analysis, p. 124). At this quarry much of the feldspar of the graphic granite is crystallographically continuous with large masses of pure feldspar, and much of the quartz of the intergrowths may be traced into the large pure areas. Graphic granite of similar composition and coarseness (No. 23, W. and L.) collected by the writer from the Andrews feldspar quarry in Portland, Conn., also showed high-temperature characters. Concordant results were obtained on quartz of graphic granite from the Urals in Russia.

Application to Maine pegmatites.—The results of these several tests are consistent among themselves and in accord with the order of crystallization of various portions of the pegmatite as established by field evidence. Though it is not safe to draw sweeping conclusions from the rather small number of tests they are nevertheless very suggestive and render it highly probable that, although many of the finer-grained pegmatite masses and most of the graphic intergrowths of the coarser pegmatites crystallized at temperatures above 575° C., the coarser and more siliceous portions—the portions characterized by the cavities and hence presumably richer in gaseous or fluid constituents—crystallized at temperatures below 575°. The portions characterized by high and by low temperature quartz are commonly so intimately associated in the same pegmatite mass that it seems unreasonable to assume great differences in the temperature of crystallization of different portions. It is probable, therefore, that the whole mass of many of the coarser pegmatites crystallized not far from the inversion point of quartz; that is, not far from 575° C.

EUTECTICS IN PEGMATITES.

Largely as a result of the extensive studies of Vogt,[a] many geologists[b] have been led to attribute to eutectics an important part in rock formation. One of the phenomena[c] that most obviously sug-

[a] Vogt, J. H. L., Die Silikatschmelzlosungen, vol. 2, 1903, pp. 117-135.
[b] Harker, Alfred, The natural history of igneous rocks, pp. 262-266, 270-272.
[c] Teall, J. J. H., British petrography, 1888, pp. 401-402.

gested such a relation was the graphic structure exhibited by many pegmatites, which closely resembled patterns formed by eutectic mixtures in alloys. Vogt[a] calculated the ratio between quartz and feldspar in a number of analyses of graphic intergrowths of quartz with microcline, the latter mineral being also perthitically intergrown with various amounts of soda plagioclase. The ratios were constant enough to lead Vogt to conclude that the graphic granites represented eutectic mixtures. Slight disparities between analyses he attributed to slight variations in the compositions of the feldspars and to variations in the pressures under which the granites had crystallized. In many specimens, especially in microscopic varieties, the graphic intergrowths are considered to be the end products of crystallization.

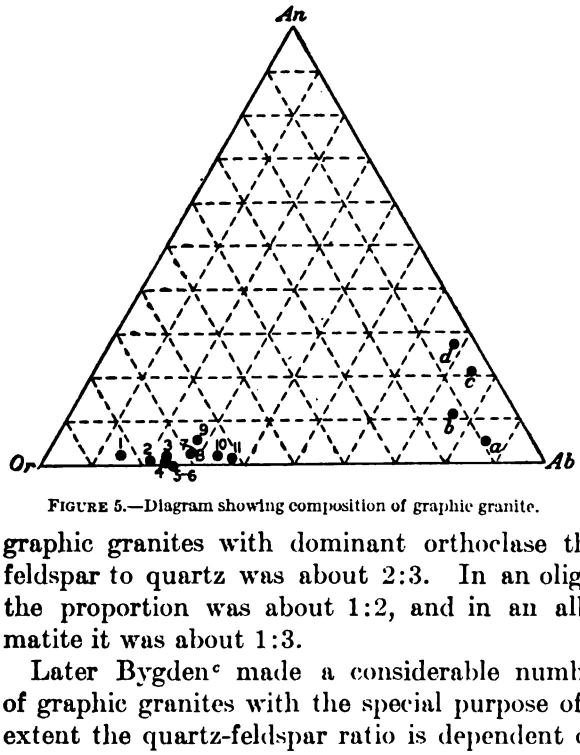


FIGURE 5.—Diagram showing composition of graphic granite.

In 1905 H. E. Johansson,[b] working mainly with Vogt's analyses, computed the molecular proportions of the quartz and feldspars present and concluded that these bore very simple numerical relations to each other. In graphic granites with dominant orthoclase the molecular ratio of feldspar to quartz was about 2:3. In an oligoclase graphic granite the proportion was about 1:2, and in an albite-quartz micropegmatite it was about 1:3.

Later Bygden[c] made a considerable number of other analyses of graphic granites with the special purpose of determining to what extent the quartz-feldspar ratio is dependent on the composition of the feldspar. He concluded that the ratio between quartz and feldspar bore no *regular* relationship to the composition of the feldspar. He believed that in most graphic granites definite ratios did exist between the proportions of feldspar and quartz, but that these ratios were not always so simple as Vogt and Johansson had supposed.

To supplement the small number of available trustworthy analyses the writer collected specimens of graphic granite from the Fisher

[a] Op. cit., pp. 120-121.
[b] Geologiska föreningens förhandlingar, Stockholm, vol. 27, 1905, p. 119.
[c] Bygden, A., Über das quantitative Verhaltnis zwischen Feldspat und Quartz in Schrift-graniten: Bull. Geol. Inst. Univ. Upsala, vol. 7, 1904, pp. 1-18.

feldspar quarry in Topsham, Me., and from Kinkle's feldspar quarry in Bedford, N. Y. These were analyzed by George Steiger in the laboratory of the United States Geological Survey. (See p. 124.) In order that the material analyzed should represent closely the true composition, about 10-pound samples of the Maine granites were taken. These were pulverized, carefully mixed, and quartered down to convenient size for analysis. The New York specimen was a cleavage piece about 1 by 2 by 3 inches in size.

The ratio of quartz to feldspar in the analyses published by Vogt and Bygden and in the author's analyses are given in the table below. In figure 5 the compositions of the feldspars are plotted on triangular projection. The numbers in the diagram correspond to those in the table.

Composition of graphic granites.

No.	Locality.	Feldspar.[a]	Quartz.[a]	Molecular percentages of feldspar components.			Reference.
				Orthoclase.	Albite.	Anorthite.	
		Per cent.	*Per cent.*				
1	Skarpö	70.5	29.5	82.5	15.1	2.4	Bygden No. 7.
2	Hitterö	66.0	34.0	77.6	21.6	.8	Bygden No. 8.
3	Voie, Arendal	74.7	25.3	73.8	24.0	2.2	Vogt No. 1.
4	Elfkarleö	79.2	20.8	74.8	24.5	.7	Bygden No. 6.
5	Topsham, Me	72.9	27.1	74.4 (Nos. 5 and 6)	25.6 (Nos. 5 and 6)	None. (Nos. 5 and 6)	See p. 112.
6	do	73.7	26.3				
7-8	Hitterö	75.3	24.7	69.1	28.5	2.4	Vogt Nos. 2 and 3.
9	Reade	72.7	27.3	66.1	28.2	5.7	Vogt No. 4.
10	Arendal	76.5	23.5	63.9	33.7	2.4	Vogt No. 5.
11	Bedford, N. Y	76.8	23.2	61.7	37.0	1.3	See p. 112.
A	Rödö	56.0	39.0	9.6	85.4	5.0	Bygden No. 9 (Holmquist).
B	Evje	68.3	31.7	12.4	76.0	11.6	Vogt No. 6.
C	Ytterby	62.1	37.9	4.3	74.5	21.2	Bygden No. 11.
D	Beef Island	81.7	18.3	4.6	68.0	27.4	Bygden No. 12.

[a] Calculated from the analyses.

From the table and diagram it is at once evident that even among those graphic granites whose feldspars are almost identical in composition (such as Nos. 2 to 6) there are quite considerable variations in the quartz-feldspar ratio. In analyses Nos. 1, 2, 3, 7, 8, 10, and 11 (particularly in Nos. 1, 3, 7, 8, and 10) the percentage of anorthite is small and nearly constant, the only important variation being in the ratio between orthoclase and albite. No regular or consistent relationship is recognizable, however, between this ratio and the ratio between quartz and feldspar. The grouping of Nos. 1 to 11 near the lower line of the diagram signifies merely that the feldspar associated with the orthoclase (or microcline) in graphic granites as in normal granites[a] is usually albite or oligoclase.

Both analyses and microscopic studies show that most graphic granites are mixtures of three minerals—quartz, orthoclase or

[a] Clarke, F. W., The data of geochemistry: Bull. U. S. Geol. Survey No. 330, 1908, p. 369.

microcline, and a member of the isomorphous series of plagioclase feldspars. It should be pointed out, moreover, that if water or other gases were present, as it is almost certain they were, they formed additional components whose amount the analyses do not reveal, but whose influence on the proportions of the other constituents may have been great. If graphic granites crystallized from magmas of eutectic proportions these were therefore eutectics of at least four components. The series of analyses (p. 41), though suggesting that the proportions between the constituents of graphic granites are controlled by *some* laws, can hardly be regarded as proving their eutectic origin. The theoretical value of such analyses in elucidating the laws governing rock solutions is impaired by the fact that they take no account of the gaseous components of the magmas.

Vogt[a] states that many graphic intergrowths, especially when developed on a microscopic scale, represent the last portions of the magma to crystallize. This fact he cites as in harmony with the conception that they represent eutectic residues. Although this may be the true relation in some cases, in others the graphic granite was unquestionably not the last crystallization from the magma. In the Fisher feldspar quarry in Topsham, for example, where large masses of graphic granite pass gradually and irregularly into large areas of pure quartz and feldspar, the tests of Wright and Larsen (see p. 39) have shown that the quartz of the graphic intergrowths crystallized above 575° C., whereas the quartz of the large pure areas crystallized below 575°. The latter was therefore the later crystallization. Almost all the gem and cavity bearing portions of the Maine pegmatites grade into normal pegmatite containing abundant graphic granite. From the presence of cavities and of the rare minerals, from the general field relations, and from the fact that the quartz of the pockets and of the gem-bearing portions, wherever tested, is of the low-temperature variety, there can be no reasonable doubt that these gem and cavity bearing portions rather than the bordering graphic portions were the last parts of the pegmatite to crystallize.[b]

In considering the significance of the graphic intergrowths found in pegmatite, it is necessary to consider not only the intergrowths of feldspar and quartz, but also the almost equally regular intergrowths of muscovite and quartz, garnet and quartz, black tourmaline and quartz, etc. As muscovite, tourmaline, and garnet are less abundant than feldspar in the pegmatites, their intergrowths

[a] Op. cit., pp. 118-123.

[b] In the tourmaline-bearing pegmatites of California (according to W. T. Schaller, oral communication) the zones characterized by cavities and by the presence of the gems and other rare minerals, which were almost certainly the last portions to crystallize, grade laterally without sharp break into graphic granite which borders one wall of these pegmatite masses. Occasional stringers of pegmatite bearing lithium minerals branch off from the main gem-bearing layer and cut the bordering graphic granite.

with quartz are also less abundant and are usually of smaller size. Such intergrowths occur, however, scattered irregularly through practically all of the coarser pegmatite masses. If the eutectic be considered, as usual, as the residue of uniform composition and minimum freezing point which is the last portion to crystallize, it is manifestly impossible to regard each of these intergrowths as representing a eutectic mixture, unless indeed several portions of the pegmatite magma are regarded as crystallizing more or less independently of the remainder of the mass.

MINERALOGICAL PROVINCES.

It has already been pointed out that most of the known pegmatites which are rich in sodium and lithium minerals—that is, most of the gem-bearing pegmatites—are restricted to a zone about 25 miles long and 8 to 9 miles in width extending in a northwesterly direction from Auburn in Androscoggin County to Greenwood in Oxford County. A second and much smaller area includes the Newry and Black Mountain localities in the northern part of Oxford County and differs from the larger area in that the gem minerals are embedded in the solid pegmatite and are not in pockets. Within both areas the lithium-bearing phases form only a small proportion of the pegmatite present, most of which has the normal composition. The occurrence locally of certain masses of unusual composition is to be attributed either to the existence in the magma of sodium and lithium in very minute excess over their percentages in bordering pegmatite magmas, or else to differing degrees of segregation in magmas whose average composition was similar. As already explained, quartz associated with lepidolite and clevelandite from the gem-bearing portion of one of these pegmatites showed low-temperature characters, and the unusual abundance of pockets indicates that these portions were richer than the normal in gaseous constituents, probably mainly water vapor. In general, therefore, the gem-bearing pegmatites were characterized by a higher percentage of sodium, lithium, and phosphorus than the normal pegmatites, and probably by more water vapor and a slightly lower temperature of crystallization.

The region characterized by pegmatites rich in fluorine minerals but not in lithium minerals forms an area only a few miles across in the town of Stoneham and bordering parts of other towns in Oxford County, Maine, and Chatham, N. H.

GEOGRAPHIC RELATIONS.

The broad geographic relationships of the granites and pegmatites are also significant of their relationship and origin. As may be seen from Plate I, many of the granite areas of the eastern portion of Maine are characterized by *sharp* boundaries, and most of the granite areas of southwestern Maine show very *indefinite* boundaries and are bordered by large areas of slates and schists which have been intruded by various amounts of granite gneiss and pegmatite and by some granite and diorite. The contrast between the two types of contacts is well shown within the Penobscot Bay [a] and Rockland [b] quadrangles. In many parts of the former area, notably along the granite-schist contact from Bluehill village northward and from Bluehill Falls southwestward to Sedgwick, the granite preserves its normal medium grain up to the exact contact. In most places this contact is so sharp that it is possible to stand with one foot resting upon typical Ellsworth schist and the other foot resting upon normal granite. Dikes and irregular intrusions of granite are not very abundant in the schists near the main granite masses, and flow gneiss, pegmatite, and basic differentiations from the granite magma are almost entirely absent. In the Rockland quadrangle, on the other hand, the contact relations are wholly different, the change from pure granite to pure sediments taking place gradually through a transition zone of contact-metamorphosed and injected sediments 2 to 3 miles in width. These transition zones include a great variety of rocks, slate, schist, injection gneiss, flow gneiss, diorite, diabase, pegmatite, and granites of various textures all associated in a manner so that it is impracticable to delineate them separately in ordinary geologic mapping. In western and southwestern Maine these transition zones are much broader than in the Rockland quadrangle and contain larger amounts of pegmatite and granite gneiss and smaller amounts of basic igneous rocks.

The contrast between the sharpness of certain granite contacts observed in the Bluehill region and the very gradual transitions observed in the Rockland quadrangle and farther southwest seem to be best explained on the hypothesis that the broad injected zones represent portions of the "roof" of granite batholiths, whereas the sharp contacts represent the sides of similar batholiths. The character of the rocks found in the two types of contacts lends support to this view. The fact that water gas and other gases and their dissolved substances escape upward more readily than they do laterally may explain the great abundance of pegmatite in the broad transition zones, inasmuch as the presence of such gases is believed to be the most important factor in the development of pegmatitic texture. It is a reasonable supposition that basic differentiation from the granitic magma would also be more rapid upward than laterally, and the abundance of diabase and diorite in certain of the transition zones may thus be accounted for. The hypothesis is also in accord with the low temperatures at which certain portions of the pegmatites appear to have crystallized in comparison with the temperatures of

[a] Folio 149, Geol. Atlas U. S., U. S. Geol. Survey.
[b] Folio 158, Geol. Atlas U. S., U. S. Geol. Survey.

crystallization of normal granites; it also accords with the presence of numerous dikes of very fine-grained granite, some so fine as to be rhyolitic in certain of the contact zones, and with their absence about the sharper contacts.

SUMMARY.

Field and laboratory studies of the Maine pegmatites indicate that all are in a broad way contemporaneous and are genetically related to the associated granites.

External conditions, though locally having some slight influence, are not primarily the cause of the pegmatitic textures. The presence of the rarer elements seems to have had only a minor influence on the texture, for in many typical pegmatites such elements appear to be entirely absent. Theoretical considerations and the presence of miarolitic cavities in certain pegmatites point to the gaseous constituents of the pegmatite magmas, especially water vapor, as the primary cause of their textures.

Although certain facts, such as the pinch and swell phenomena observed in many pegmatite dikes in contrast with the parallel-walled character of most of the granite dikes, indicate somewhat greater mobility in the pegmatite than in the granite magmas, other facts, such as the sharpness of many of the contacts between pegmatite and schist, the absence of absorption along any of the contacts, the presence of angular schist fragments now surrounded by pegmatite, the small proportion by volume which the cavities bear to the whole pegmatite mass, the absence of notably greater contact-metamorphic effects near pegmatite than near granite contacts, and the batholithic dimensions of some pegmatite bodies, all suggest that the difference in average composition between the granite pegmatites and the normal granites was relatively slight and that the pegmatite magmas were not so greatly different in physical characters from the granite magmas as has been commonly supposed.

In his text-book on igneous rocks [a] Iddings, in discussing the pegmatites, says "the amount of gases concentrated in such magmas was not many times that of the gases originally distributed throughout the magma from which the pegmatite was differentiated; possibly not more than ten times as much." The present writer would be inclined, in the case at least of the granite pegmatites of New England, to estimate the gaseous content of these rocks at a still lower amount.

The experiments of Wright and Larsen on quartz from pegmatites from Maine and elsewhere indicate that some at least of the coarser pegmatites began to crystallize at a temperature slightly above the inversion point of quartz (about 575° C.) and completed their crystal-

[a] Iddings, J. P., Igneous rocks, vol. 1, 1909, p. 276.

lization somewhat below this temperature. It is probable that many of the finer-grained pegmatites crystallized wholly above 575° C.

The theory that the graphic intergrowths in pegmatites represent eutectic mixtures can not be regarded as proved by the published analyses. Certain field evidence is unfavorable to the eutectic theory.

The broader field relations suggest that the large areas characterized by particular abundance of pegmatite intrusions constitute in reality the roofs overlying granite batholiths. Where more extensive erosion has exposed the flanks of such batholiths, pegmatite masses in the bordering schists are not abundant.

LOCAL DESCRIPTIONS.

ANDROSCOGGIN COUNTY.

AUBURN.

CHARACTER AND DISTRIBUTION OF THE PEGMATITE.

Large areas in the town of Auburn, especially in the valleys of Androscoggin and Little Androscoggin rivers, are covered with sands of glacial origin which obscure the bed rock. Wherever the latter is exposed, however, it is found to be either quartz-mica schist or pegmatite intrusive in the schist or a coarse gneiss resulting from a very intimate injection of the schist by pegmatite.

Auburn Falls.—The prevailing rock types and the relationships between them are well shown in the river bed at the falls just above the bridge between Auburn and Lewiston. (See p. 11 and Pl. III, *B*.) The purplish-gray quartz-mica schists, which dip about 30° NE., in many places show distinct bedding and are of undoubted sedimentary origin. They are similar in every way to those at the Auburn reservoir. The pegmatite masses are intruded in general parallel to the trend of the schists. Just below the bridge both schists and pegmatite are cut by a dike of fine-grained diabase 3 to 4 feet wide.

The largest pegmatite mass exposed crosses the river bed at the falls, which are a result of the superior resistance to erosion offered by this pegmatite and its bordering intensely injected schists as compared with the ordinary phases of the schists. This pegmatite sill has a maximum thickness of about 20 feet and extends nearly across the river bed, though it forks at several places. It preserves about the same coarseness in the wide and narrow parts and in the center and next the walls. Its contact with the schist is everywhere sharp, and there is not the least evidence here or anywhere in this vicinity of any absorption of schist by the pegmatite.

Auburn reservoir.—Fresh exposures of the schists were also beautifully shown at the new reservoir site on Goff Hill in Auburn. This reservoir was under construction at the time of the writer's visit, and many exposures then showing have since been covered. The schists, which in general are purplish gray in color, have been intensely injected by pegmatite, though the largest pegmatite lens observed was 10 feet long and 2½ feet in greatest width. The injection does not in all places take the form of definite lenses or stringers of pegmatite, but in many the impregnation of the schist is so intimate as to obscure almost entirely the schistose structure and develop a speckled appearance. The sedimentary origin of the schist is shown by the general evenness and regularity of its trend and by the local preservation of bedding in its more quartzose layers.

Danville Corners.—An exposure of considerable interest was observed in a road cut about half a mile southeast of Danville Corners, where the rock, which has been recently blasted, is for the most part a gray granite of slightly gneissic texture. It is phanerocrystalline, most of its mineral grains ranging from 1 to 2 millimeters in diameter and its texture is typically granitic. The faint gneissic texture is due to a parallel orientation of many of the biotite plates, to their slightly greater abundance along some planes than along others, and to slight differences in the coarseness of certain bands as compared with others. Under the microscope the constituents are seen to be quartz, orthoclase and microcline, albite, biotite (altering to chlorite), and some muscovite, their relative abundance appearing from casual examination to be in the order given.

This granite gneiss is associated with subordinate amounts of pegmatite, which is not so coarse as much pegmatite found elsewhere, but is typically pegmatitic in texture. The pegmatite specimen collected for detailed study shows feldspar crystals up to one-half inch across and aggregates of feldspar crystals unmixed with other constituents 1 inch across and areas of smoky quartz one-half inch across. Muscovite crystals are one-eighth inch across and biotite crystals one-fourth inch. Garnets up to one-sixteenth inch in diameter occur. Texturally the pegmatite differs from the granite gneiss in showing a much greater range in size in the mineral grains of each species and much less evenness in their distribution. In the pegmatite there is a marked tendency toward segregation of the different mineral constituents, some areas being dominantly feldspar and others dominantly quartz. This feature is entirely distinct from mere increased coarseness of grain.

The constituents of the pegmatite are identical with those of the granite gneiss, being (1) quartz, (2) orthoclase and microcline, (3) oligoclase-albite with some border rims of albite, (4) biotite, and (5) muscovite, the numbers showing the order of their apparent abundance. The principal difference in their mineral composition is the much smaller quantity of biotite present in the pegmatite. Inclusions are abundant in the quartzes of both rocks and are of about the same size. The majority are under 0.005 millimeter, but a few are over 0.01 millimeter in greatest dimension. They are not notably more abundant in the pegmatite than in the granite gneiss.

In a few places the pegmatite is rather sharply delimited from the granite gneiss in dikelike masses, but for the most part it occurs in the granite in lens-shaped or roughly spheroidal masses from a few inches to a foot or more across, coarsest in the center and grading very gradually with increasing fineness into the surrounding granite gneiss. A few of the pegmatite "bunches" show a center composed largely of quartz, surrounded by a zone in which feldspar is dominant. In places the pegmatite masses send off irregular and vaguely bounded ramifications into the granite gneiss. The two types are associated in the most irregular manner. In places the pegmatite is very coarse and carries beryl and black tourmaline. One feldspar crystal in this portion measured 8 inches across.

The relation and mineral characters detailed above suggest the following inferences in regard to the genesis of the rocks described:

1. The presence of the same mineral species in the same order of abundance in both rocks and the many instances of complete gradation of one rock into the other show that they are products of the same parent magma.

2. The fact that the pegmatite masses in some parts of their length have rather sharp walls and in other parts grade gradually into the granite gneiss indicates that certain portions of the pegmatite crystallized after some of the granite was rigid enough to develop cracks into which the pegmatite magma penetrated, and that at the same time other parts were fluid enough to permit pegmatite and granite to solidify with gradual gradation and perfect crystallographic continuity between them.

3. The intimate and small-scale manner in which the pegmatite and the granite gneiss are associated, and the fact that these variations are so irregular and are not related in any way to any wall rock now observed or probably existent in the past, suggest that the causes operative in producing the variations in texture and composition were not of external origin, but were inherent in the magma itself.

Danville Junction.—In the extreme western part of the town of Auburn, about 3 miles west of Danville Junction, along the road to Poland Springs, conspicuous white ledges of pegmatite exemplify clearly certain common relationships of the pegmatites of this part of the State. In places this pegmatite grades gradually with perfect crystallographic continuity into a rather fine-grained granite gneiss. One pegmatitic band 1 inch wide in this granite gneiss shows contortions, which, in the absence of any regional metamorphism later than the granite-pegmatite intrusions, appear only explainable as the result of flowing movements in the granite gneiss at the time the pegmatite was intruded. A small mass of quartz-mica schist lying between two sill-like masses of pegmatite, though evidently molded somewhat during their intrusion, shows no evidence of absorption. Some of the narrower pegmatite bands in the schists can be traced continuously through portions showing successively larger proportions of quartz into "lit-par-lit" injections of pure quartz. Several diabase dikes at this locality strike N. 70° to 80° W. and dip vertical; they are about parallel to the most prominent joint planes in the granite and pegmatite.

The inferences which appear justified from the relations just described are as follows:

1. The complete and gradual gradation of pegmatite into granite gneiss and the presence of contorted bands of pegmatite in the granite indicate that portions at least of the granite gneiss were still more or less fluid when the pegmatite was intruded.
2. Certain quartz stringers in the schists are the end products of pegmatitic crystallization.
3. Neither the granite gneiss nor the pegmatite at this locality exercised any considerable absorptive action on the quartz-mica schists into which they were intruded.

Mount Apatite.—Pegmatite deposits are worked extensively for feldspar, and to some extent for minerals valuable as gems or as cabinet specimens, at Mount Apatite, a low prominence about 6 miles west of the city of Auburn near the road to Minot, and about 2 miles from Littlefield, the nearest railroad station on the Lewiston branch of the Grand Trunk Railway.

The interest in Mount Apatite as a mineral locality may be said to date back to 1868, when the Rev. Luther Hills called attention to a specimen of tourmaline found by G. C. Hatch on his farm. This crystal yielded a fine 2-carat gem of light-green color, but it was not found in place, and considerable searching having failed to reveal any further crystals the property remained unworked for some years. In 1883 N. H. Perry, of South Paris, found the tourmalines in place near the Hatch farmhouse, and in that year, from an excavation about 20 by 8 feet and 8 feet deep, took nearly 1,500 tourmaline crystals, ranging from very small ones 1 centimeter long to one 10½ centimeters long. Thomas F. Lamb, of Portland, was also one of the pioneers at this locality, working intermittently for three or four years, part of the time with Loren B. Merrill, of Paris, now the proprietor of the Mount Mica tourmaline mine. He found a considerable number of gem tourmalines and some remarkably handsome groups of crystals of smoky quartz, besides much valuable cabinet-specimen material.

After the expiration of the leases of the persons mentioned, no mining of importance was done at Mount Apatite until 1902, when the Maine Feldspar Company, now the largest operator at this locality, commenced mining feldspar for use in pottery manufacture. Previously small amounts of quartz had been mined and shipped for use in the manufacture of sandpaper, and it is interesting to note that at this time the feldspar was considered to be of no value and was thrown on the dump piles. Although a few gems and cabinet specimens have been found in the course of the feldspar mining and by collectors paying short visits to Mount Apatite, regular mining for gems was not resumed until 1907, when J. S. Towne commenced operations at a new locality (p. 55).

QUARRIES.

Maine Feldspar Company quarry and mill.—The largest workings at Mount Apatite are those of the Maine Feldspar Company, of Auburn, which commenced operations in 1902 and has operated continuously to the present time (1909). The property was visited by the writer in August, 1906, and again in October, 1907.

The workings consist of a number of small pits 75 to 150 feet long, 50 feet in average width, and 10 to 20 feet in depth. These are either close together or partly connected and are located in a single mass of pegmatite which constitutes the summit of the hill. Much of the hilltop is bare, but in a few places as much as 6 feet of clayey till must be stripped in working.

The minerals present are those usually found in the granite pegmatites of the Atlantic States which are worked for feldspar but include many others that are characteristic only of the gem-bearing pegmatites.

Quartz varies from white to dark gray in color and from opaque to beautifully transparent. Its commonest occurrence is in graphic intergrowth with feldspar, but it is found also in large pure masses and in clusters of beautiful crystals projecting inward from the walls of pockets or fallen into the mass of kaolin, cookeite, etc., at their bottoms. Many of these groups of crystals are colorless and transparent, but others, notably some found by Thomas F. Lamb in one of the early workings near the Hatch farmhouse, though transparent, are smoky. Some of these latter are 20 centimeters in length and many are coated, especially at the tips of the pyramids, with thin white opaque quartz, which is plainly of more recent development than the main mass of the crystal. A few of the quartz crystals of the pockets are penetrated by small colored tourmaline crystals. The quartz obtained in the course of the present mining for feldspar is white and very pure and is of excellent quality for any of the many purposes for which crystalline quartz is now used. It is saved in stock piles, where it is allowed to accumulate until a sufficient amount is obtained to make its shipment worth while. The profit is very small in handling quartz so far from the principal markets in the Middle Atlantic States. At the time of the writer's visit, in 1906, about 300 tons of it was lying in stock piles.

The feldspar is mostly buff to cream colored with local bluish-gray spots and streaks due to minute inclusions. Microscopic study shows it to consist of the potash varieties, orthoclase and microcline, minutely (perthitically) intergrown with small amounts of the soda feldspar, albite. In certain narrow and irregular bands in the pegmatite, albite of a dirty olive-green color in irregularly bounded crystals up to 2 inches in length is almost the only feldspar present and is associated with quartz and muscovite. As is usual in all feldspar quarries, most of the material marketed under the commercial name "feldspar" is a graphic intergrowth of feldspar and quartz, though whatever pure feldspar may be found is mixed with this. In those portions of the pegmatite which bear pockets, the white-bladed variety of albite known as clevelandite is very abundant in radiating aggregates of thin plates. The standard or No. 2 grade obtained at this quarry consists principally of graphic granite with a subordinate amount of pure feldspar. Some No. 1 grade nearly free from quartz is also obtained; an analysis of a sample of this, made in the laboratory of the United States Geological Survey, is given below.

Analysis of No. 1 ground feldspar from Auburn, Me.

Silica (SiO_2)	65.73
Alumina (Al_2O_3)	[a] 19.28
Magnesia (MgO)	None.
Lime (CaO)	.22
Potash (K_2O)	10.26
Soda (Na_2O)	4.08
Water (H_2O)	.48
	100.05

The mineral composition of this sample, as calculated from the analysis, is as follows:

Mineral composition of No. 1 ground feldspar from Auburn, Me.

Quartz	2.22
Orthoclase and microcline	60.60
Albite	35.69
Water	.48
Other constituents	1.02
	100.01

Muscovite is moderately abundant, but almost none of it is in clear transparent plates. Most of it is of the A variety (see p. 139) and some of the bladelike books are as much as a foot in length. It is common

[a] Includes traces of iron and any TiO_2 and P_2O_5 that may be present.

in graphic intergrowths with quartz. As described below, some small clear muscovite prisms are surrounded by a border of lepidolite. Mr. Lamb has also found some fine curved crystals of muscovite.

Biotite is abundant only locally and can in most areas be readily avoided in mining the feldspar. It forms typical lath-shaped crystals.

Lepidolite is not very abundant, but some occurs especially associated with clevelandite and muscovite near pockets. It is present in granular aggregates of small plates and prisms (in many places intergrown with some quartz) and also in larger plates. Its occurrence as narrow borders surrounding muscovite and in crystallographically parallel growth with it has been fully described and figured by Clarke,[a] who gives analyses of both of the muscovite and the lepidolite border.

Garnets of small size occur sparsely in all parts of the pegmatite. They are most abundant in the more quartzose and micaceous parts and are not present in injurious amounts in the more highly feldspathic portions.

Black tourmaline is present in all those portions of the pegmatite which carry colored tourmalines but is only locally abundant and is not particularly bothersome in feldspar mining. Most of the colored tourmalines which have been obtained have come, not from the feldspar workings, but from small pits near the Hatch farmhouse, worked at an earlier date solely for their gems and mineral specimens. Those found in 1883 by N. H. Perry ranged from 1 centimeter to 10½ centimeters long, and differ from the majority of the Maine tourmalines in being mostly of lighter color. They were found colorless, light pink, lilac, light blue, light puce colored, bluish pink, and light green, some single crystals showing nearly all these colors. Gems from some of the paler crystals are said to have deepened very much in color after cutting. The majority of these crystals, of which nearly 1,500 were obtained, were more or less flawed. Some of the tourmalines found later by Mr. Lamb were cut into gems of emerald-green color.

Crystals of light bluish-green beryl also occur rather abundantly, embedded in the solid pegmatite. One hexagonal beryl found about 1898 is reported by J. S. Towne to have been 4 feet in diameter and 20 feet in length, but the majority do not exceed 1 foot in length and a few inches in diameter. Near the gigantic beryl mentioned occurred several pockets bearing the finest crystals of herderite ever found on Mount Apatite; the form and composition of these have been described by Penfield.[b]

Apatite occurs occasionally in crystals of fine luster and transparency, the colors being light pink, purple, light blue, and blue

[a] Clarke, F. W., The lepidolites of Maine: Bull. U. S. Geol. Survey No. 42, 1887, pp. 15-17.
[b] Penfield, S. L., Herderite from Auburn, Me.: Am. Jour. Sci., 3d ser., vol. 47, 1894, p. 336.

green. The crystals occur singly or in groups and vary in size from 1 mm. to 15 mm. long and from 1 to 20 mm. wide.

Other minerals reported [a] from Mount Apatite are allanite, amblygonite, autunite, cassiterite, columbite, cookeite, damourite, gummite, magnetite, molybdenite, triplite, and zircon.

Neither the exact form nor the area of the pegmatite body could be determined, but it occupies practically the whole top of Mount Apatite, and it is probable that further stripping of the soil in the neighborhood of the present workings will disclose considerable amounts of commercially valuable feldspar and possibly portions valuable enough to be worked for their gem minerals. The presence in the pegmatite of one of the northern pits of a 2-foot band of epidotized altered quartzite which is nearly flat lying and is regarded as a remnant of the sediments into which the pegmatite was intruded, and the presence in other pits of this quarry and in the neighboring quarries of nearly flat-lying bands particularly rich in small garnets, both indicate that the general attitude of the whole pegmatite mass is rather flat lying.

On the floor of one of the pits is exposed an instructive cross section of a dike of pegmatite cutting the main pegmatite mass. This dike is a foot in width and cuts graphic granite whose usual variations of texture are wholly unaffected, although the two rocks show crystallographic continuity along the immediate contact. The dike at its borders is mainly feldspar, the separate more or less blade-shaped crystals being disposed at right angles to the walls. The center of the dike is an irregular band of light-gray quartz. The dike was probably intruded soon after the partial or complete solidification of the main mass of pegmatite under conditions favoring more segregation of the quartz and feldspar than usually took place. Only one other dike of similar character was observed by the writer in the course of two months' field study. Their rarity argues for the essential contemporaneity of most of the pegmatite intrusions.

Pockets are of rather rare and irregular occurrence and are found only in the coarser portions of the deposit. Very few were observed by the writer. Most of them are said to be under 1 foot in diameter, but one about 4 by 6 by 5 feet in size is said to have been found. Clear crystalline quartz is the commonest mineral found in the pockets, though some tourmalines and beryls of gem quality and crystals of herderite occur. Here, as at other localities, the clevelandite variety of albite is common near the pockets.

Several dikes of typical fine-grained diabase, whose minerals under the microscope show only slight alteration, cut the pegmatite. One observed was 20 feet in width and another 6 feet in width.

[a] Kunz, G. F., On the tourmalines and associated minerals of Auburn, Me.: Am. Jour. Sci., 3d ser., vol. 27, 1884, pp. 303-305.

The topographic situation of this deposit on the crest of the hill favors the ready disposition of the waste from the quarries and also provides a down-hill haul most of the way from the quarry to the mill. The excavating is accomplished by steam drilling and blasting, the material then being broken up with sledges and picked over by hand. It is hauled 2 miles by teams to the mill at Littlefield station. The usual force consists of a foreman and 10 laborers.

The feldspar quarried at Mount Apatite is ground at a mill located at the side of the Grand Trunk Railway at Littlefield station. The ground spar is loaded directly into cars at the mill and shipped in bulk mainly to potters at Trenton, N. J., and East Liverpool, Ohio. The equipment consists of one chaser mill, in which each stone weighs about 3½ tons, and a ball mill, which is larger than that used at most feldspar mills, grinding 3 tons at a load; the capacity of the plant is about 15 tons in twenty-four hours. Eight men and a foreman are employed. The power is supplied by a 75-horsepower Westinghouse motor, the current coming from a power plant on Androscoggin River.

Turner feldspar quarries.—Three small pits on the southern part of the summit of Mount Apatite have been worked intermittently during the past ten years by E. Y. Turner, of Auburn, the product being ground principally at the mill of the Maine Feldspar Company. The quarries were idle at the time of the writer's visits in 1906 and 1907, but had been worked more or less at other times during these years. The total amount of material which has been taken out is small.

The westernmost pit is a nearly circular opening 25 feet in diameter and about 10 feet in maximum depth. Most of the rock is crowded with blades of biotite and is therefore commercially valueless, though a small amount of feldspar free from iron-bearing minerals is exposed on the floor of the pit. Some black tourmaline occurs, and rosette-shaped graphic intergrowths of quartz and muscovite are common.

The easternmost pit is about 75 feet long by 30 feet wide and 10 feet in maximum depth. At this pit two distinct bands, rich in small, dark-red, opaque garnets, run through the pegmatite; they are from 1 to 6 feet apart and dip about 15° NW. Another zone about 1 foot thick lying just above the garnetiferous zone is particularly rich in black tourmaline, and above this is a 4-foot zone which shows an unusual profusion of muscovite and biotite crystals. The 5 feet of pegmatite below the garnetiferous bands contains much feldspar of good commercial quality, iron-bearing minerals being rare. None of the upper layers at this quarry will yield feldspar suitable for pottery purposes, and the expense of removing the upper layers would probably render it unprofitable to work the layer of better quality at the bottom of the pit.

A third small pit, 40 by 40 feet and 8 feet in average depth, just north of the one described, shows some feldspar of commercial grade, as does also a small prospect pit on the southeastern slope of the hill. In the unopened natural exposures near these quarries practically all the rock is too fine grained or too rich in muscovite or iron-bearing minerals to be valuable for pottery purposes. As far, therefore, as can be judged from the present exposures these quarries show little prospect of yielding much feldspar of pottery grade. The material may ultimately prove of value for poultry grit, fertilizer, or other uses where iron-bearing minerals are not detrimental.

The pegmatite of these quarries, though of poorer quality commercially than that at the quarries of the Maine Feldspar Company, appears to form a part of the same large pegmatite mass. The excavating has been in part by hand drilling and blasting and in part by steam drilling. The equipment includes a small derrick.

Towne feldspar and gem quarry.—In April, 1907, a quarry was opened by J. S. Towne, of Brunswick, Me., on the Pulsifer farm about one-half mile northwest of the Maine Feldspar Company's quarries on Mount Apatite. This quarry is operated by the Maine Feldspar Company for feldspar, the gems found being handled by Mr. Towne.

The workings were visited by the writer in October, 1907, at which time they consisted of three very small pits all on the same half acre. All are in pegmatite but only two expose the pockety or gem-bearing zone. The third pit is higher on the hill slope, and has not yet got down to the pocket-bearing layer; in the lower pits it has penetrated it for 4 feet but has not yet reached its base. The gem-bearing layer, though grading gradually into the other pegmatite, is distinguishable from it not only by the presence of pockets but by being somewhat coarser than other portions of the pegmatite. It is characterized by the presence of clevelandite, lepidolite, and green tourmaline embedded in the solid pegmatite, the usual "indicators" of proximity to gem tourmalines. The pocket-bearing layer appears to dip about 10° E. The bordering schists are not exposed in the vicinity of this quarry.

The feldspar obtained from these pits is similar to that mined at the Maine Feldspar Company's quarry, and of equal value. Black tourmaline is abundant near many of the pockets, as is also green tourmaline in semitransparent crystals up to one-eighth inch in diameter, penetrating or interleaved with muscovite. As at most localities where gem tourmalines are found, biotite is almost entirely absent. Garnets are not abundant in the pocket-bearing layer, though fairly abundant in the bordering phases of the pegmatite. Lepidolite occurs both in granular aggregates of small scales and prisms and in large curved crystals with rounded botryoidal surfaces one-half inch to 1½ inches across; many of its curved crystals are interlaminated with the bladelike crystals of snow-white clevelandite or are partly embedded in light-gray, more or less transparent quartz. Amblygonite occurs in the solid pegmatite in irregular masses, some of them 6 to 8 inches across. Some small crystals of columbite, cassiterite, and rhodochrosite occur, but their crystal faces are usually only imperfectly developed. One crystal of zinc spinel of perfect form, five-eighths inch in diameter, was found embedded in the feldspar. At the time of the writer's visit only two gem-bearing pockets had been found. One of these bore dark grass-green tourmalines and the other light-green tourmalines tipped with opaque pink. The largest of the dark-green tourmalines was about three-fourths inch in diameter and 1½ inches long but was badly flawed. A number of other pockets bore only crystals of transparent quartz. Some fine specimens of herderite have also been found at this locality. This mineral occurs in short prisms, few of them over one-fourth inch long, commonly as an incrustation on the quartz crystals of the pockets. One short stout crystal attached to muscovite was as large as the end of one's thumb. This mode of occurrence is similar to that observed at Stoneham, where it was first discovered, and there can be little doubt that it was formed through gaseous or aqueous deposition after the solidification of the main pegmatite mass.

The feldspar obtained at this locality is hauled 2 miles for grinding to the mill of the Maine Feldspar Company. The gem tourmalines are cut and sold, principally in Maine, by Mr. Towne.

Wade and Pulsifer gem quarries.—A pegmatite mass located on the farm of P. P. Pulsifer, within 100 yards of the Towne quarry, was opened up in 1901 and was worked intermittently until 1904 for its gems and other rare minerals.

The quarry was visited by the writer in August, 1906. The original pit, opened by Mr. Pulsifer in 1901, is about 25 by 25 feet and 8 feet deep; it connects with another pit about 75 by 30 feet, with a maximum depth of 8 feet. The mineral rights at this second pit were acquired from Mr. Pulsifer by the Maine Tourmaline Company, and were worked in the summers of 1904 and 1905.[a] The two pits constitute virtually a single quarry.

The rock at this locality is practically bare, so that little or no stripping is necessary in working the deposit. The pegmatite is similar in general character to most of the gem-bearing pegmatites of the State. The main mass of the rock is a graphic intergrowth of quartz with orthoclase and microcline, showing abrupt variations in coarseness. The deposit as a whole seems to be rather flat lying, as is shown by the presence near its base of a nearly horizontal

[a] Wade, W. R., The gem-bearing pegmatites of western Maine: Eng. and Min. Jour., vol. 87, 1909, pp. 1127-1129.

garnetiferous layer, with more or less wavy upper surface, which could be traced continuously for over 50 feet. The garnetiferous band itself is nowhere over 1½ inches wide and is a rather finely granular crystallization of quartz, feldspar, and garnet, the crystals of garnet constituting about half of the band, but few of them exceeding one-fourth inch in diameter. In places the main garnet layer is paralleled below at a distance of 1 to 2 inches by another similar band less rich in garnets. Outside these bands garnet occurs in the pegmatite in graphic intergrowth with quartz and in small irregular masses between the other minerals. The pegmatite shows very different characters below and above these garnetiferous layers. The rock just above is much coarser, does not show graphic texture, and does show albite, in part massive and in part of the clevelandite variety, as its dominant feldspar, though it contains also some orthoclase in graphic intergrowth with quartz. Muscovite in brush-shaped and rosette-shaped intergrowths with quartz is also more abundant above than below the garnet layer, and black tourmaline is common in places in graphic intergrowth with quartz. The pegmatite just below the garnetiferous band is a rather fine-grained graphic intergrowth of quartz and orthoclase showing a more or less radial structure trending about at right angles to the garnetiferous layer.

Only small portions of the feldspar are of commercial grade for pottery purposes, both muscovite and biotite being quite abundant.

Quartz is mainly present in intergrowth with other minerals or as crystals developed on the walls of the pockets. Most of it is white or light gray, but some small amounts of rose quartz are found.

The muscovite commonly occurs with quartz in brush-shaped or rosette-shaped intergrowths averaging 4 to 5 inches in diameter and disposed with utter irregularity throughout the pegmatite mass. Some of these grade at their outer borders into spearhead-shaped bundles of muscovite penetrating the neighboring quartz masses, the latter being apparently continuous with the quartz of the fine muscovite intergrowths. No plate mica occurs, and the only possible utilization of the mineral is as scrap mica.

Biotite is abundant, though much less so than the muscovite. It occurs in small lath-shaped crystals, oriented in every direction in the pegmatite mass. A few are a foot long and 2 inches wide, but the majority do not average more than 2 inches long and 1 inch in width. A central "stalk" of biotite with smaller lath-shaped crystals radiating from it is not uncommon.

Lepidolite is abundant near the pockets in irregular aggregates of small plates or prisms one-sixteenth to one-eighth of an inch across, and in larger more or less curved crystals. In many places it forms narrow borders about hexagonal muscovite plates, the two varieties of mica being crystallographically continuous. Mr. Wade reports one diamond-shaped book of muscovite a foot across with a border zone of lepidolite 4 inches wide. As in the other Maine quarries in which gem tourmalines occur, the presence of the lithium mica is considered a favorable indication of the near presence of gem-bearing pockets.

Black tourmaline, as already stated, occurs in the pocket-bearing zone of the pegmatite above the garnetiferous layers. It is never found in the pockets, where all the tourmalines are colored either pink, blue green, or occasionally emerald green. Most pockets contain tourmalines of only a single color, but in some both pink and green varieties are found, and, indeed, the two colors frequently occur in the same crystal. Colored tourmalines, most of them partly or wholly opaque, also occur in the solid pegmatite near the pockets in association with lepidolite, clevelandite, and quartz, and some of these crystals are curved through angles as great as 60° or even 90°. Green tourmalines also occur intergrown parallel to the plates in the muscovite books.

The hydromica cookeite occurs principally in the pockets with quartz as a coating on lepidolite, quartz, feldspar, and tourmaline.

The tourmalines, lepidolite, and clevelandite are beyond doubt crystallizations from the original pegmatite magma. The cookeite, purple apatite crystals, and certain opaque white outer coatings of quartz on the clearer crystals of gray quartz, are believed to be later crystallizations from gaseous or aqueous solutions.

All of the pockets thus far encountered in this pegmatite have been in the portion lying above the garnetiferous bands. The portion below it seems to be wholly devoid of pockets and hence of gem minerals. No pockets were exposed at the time of the writer's visit, but those which have been encountered are said to range from a few inches to several feet in diameter. Though occurring apparently only within a nearly flat-lying pocket-bearing zone their horizontal distribution seems to be totally irregular. Their walls usually consist mainly of clevelandite, lepidolite, and quartz, but have in most cases been much weathered and shattered by frost.

The early excavations at the original Pulsifer pit disclosed a number of pockets containing beautiful and very perfect crystals of purple apatite. The form of these crystals and their mode of occurrence have been described by Wolff and Palache;[a] most of them are now in the mineralogical museum of Harvard College. The largest pocket yielded over 2 pounds of loose crystals and a dozen large groups of crystals in the matrix. Most of them occurred on or embedded in layers of the opaque white quartz which coat many of the crystals of transparent quartz in the pockets.

The distribution of the cavities is exceedingly irregular, and no prediction can be made as to the success which will attend further

[a] Wolff, J. E., and Palache, C., Apatite from Minot [should be Auburn], Me.: Proc. Am. Acad. Arts and Sci., vol. 37, No. 18, 1902, p. 515.

mining. The relations shown in the present pit seem to indicate that the trend of the garnetiferous layer above described may be taken as an indicator of the trend of the pocket-bearing portion lying just above it. Further excavation in this zone is fairly certain to disclose gem-bearing pockets, but excavation below the garnet-bearing layer has not been fruitful. Great care should be used in drilling and blasting, for injudicious placing of the drill holes and heavy blasting with dynamite are likely to shatter valuable material.

The pegmatite at this locality is cut by a dike, 2½ feet wide, of fine-grained altered diabase.

The precise value of the gems and museum specimens taken from this locality can not be determined, but so far as known to the writer, no gems of over 6 or 8 carats have been obtained. Mr. Pulsifer estimates the value of the materials taken from the pit operated by him at about $2,000.

MINOT.

In the southeastern part of the town of Minot, near the Auburn line, some pegmatite which appears to be of commercial grade occurs on the farm of Edward Hackett, where masses of practically pure feldspar, 2½ to 3 feet across, are associated with masses of pure quartz of similar dimensions. Almost no biotite, garnet, or black tourmaline was seen. The pegmatite seems to underlie a mass of finely pegmatitic granite. There is no doubt of its commercial quality, but as the present outcrops cover an area only about 100 feet or so square, it is uncertain whether the quantity would warrant mining. The locality is, however, worth prospecting.

POLAND.

A quarry located just across Androscoggin River from Mount Apatite, about 3 miles from Littlefield station, on the Lewiston branch of the Grand Trunk Railway, in the town of Poland, is operated for feldspar and occasional gem minerals by A. R. Berry, R. D. No. 7, Auburn, Maine.

The quarry was opened in 1900 and has been worked intermittently on a small scale ever since. It was visited by the writer in August, 1906. The openings, which are very irregular and cover an area of about 2 acres, are shallow open pits, none of them more than 18 or 20 feet in maximum depth.

The general character of the pegmatite is similar to that at the Maine Feldspar Company's quarries at Mount Apatite. The rock is mainly a graphic intergrowth of quartz with buff-colored microcline and some orthoclase. Some albite in irregular crystals a few inches across is encountered.

Muscovite occurs, as at the Wade and Pulsifer quarries, in brush-like and rosette-like intergrowths with quartz. No plate mica occurs, and no attempt has been made to market the material as scrap mica.

Biotite is locally very abundant, occurring as irregularly disposed blades or bundle-like masses in which thin layers of feldspar or quartz occur between the blades. Such biotitic bundles occur in association with the coarser phases of the pegmatite, and render valueless for pottery purposes much feldspar which could otherwise be used.

The lithium mica, lepidolite, occurs in the pockets and near them in the usual forms, similar to those described from the Wade and Pulsifer quarries. (See pp. 57–58.)

Black tourmaline is abundant in certain parts of the pegmatite, usually in intergrowth with quartz, one mass of intergrown quartz and black tourmaline being 10 to 12 inches across. One black tourmaline crystal observed was 5 by 12 inches in size. In the pockets no black tourmaline is found, but some emerald-green, blue-green, and pink transparent varieties occur, usually embedded in a mass of kaolin, cookeite, etc., at the bottoms of the pockets. The largest colored tourmaline obtained at this quarry was a pale-green crystal about 1½ inches in diameter. Only an inch of the base was found and it was too much flawed to cut any gems. Many of the smaller, colored tourmalines are hollow and can be strung like beads.[a] Slender flattened prisms of opaque to transparent green tourmaline occur, penetrating and interleaved with muscovite plates.

A few fine crystals of purple apatite similar to those found at the Wade and Pulsifer quarries have been obtained from some pockets. In some of the finer-grained portions of the pegmatite the writer observed numerous small vugs, rarely more than a cubic centimeter or two in volume. These were generally surrounded by albite in small bladelike crystals. Attached to or embedded in the albite at their base or along their flanks, but otherwise free, occur hexagonal prisms, from one-sixteenth to one-fourth inch in diameter, of pale greenish blue to pale lavender apatite. These plainly were among the last of the pegmatite constituents to crystallize, being in part contemporaneous with the albite and in part later. Blue-gray apatite in flat, bladelike prisms one-fourth to one-half inch across also occurs. Beryl and amblygonite occur as constituents of the solid pegmatite, as in most of the pegmatites bearing gem tourmaline. Herderite in crystals up to one-half inch in length is found in some pockets.

The distribution of pockets at this quarry is very irregular, and the writer saw no structures which indicated even in a general way the attitude of the deposit. There is unquestionably a considerable

[a] In the summer of 1910, since the above account was written, several pockets containing fine gem tourmalines were discovered by Mr. F. S. Havey in the western part of the quarry near a diabase dike. Mr. Havey was working the quarry for feldspar for the Maine Feldspar Company.

amount of commercial feldspar of pottery grade still available at the locality.

The feldspar is excavated by hand drilling and blasting, and after hand sorting is hauled by wagons 3 miles to Littlefield station, where it is sold to the Maine Feldspar Company and ground at that company's mill. Gem tourmalines and minerals of value as cabinet specimens are not encountered so frequently that it is profitable to work the deposit for them alone. In 1906 the quarry force consisted of three men. The gems and other valuable minerals obtained are marketed irregularly through local collectors, and no estimate of their value is obtainable. The feldspar output is a few hundred tons a year.

CUMBERLAND COUNTY.

BRUNSWICK.

The relations between the granite and pegmatite in the town of Brunswick is well shown at the Woodside quarry, about 2½ miles southeast of Hillside station. This is an old quarry, where granite for flagging and underpinning has been obtained. The sheeting of the granite here is very perfect and nearly horizontal.

On the south wall of this quarry much pegmatite is associated with the granite. Many of the pegmatite masses of lenticular or extremely irregular form grade into the granite in the most gradual and complete manner and are characterized by identical minerals. They differ from the granite only in texture, and there can be no question that the two rocks solidified practically contemporaneously from the same magma. Other pegmatite dikes, however, distinctly cut the granite with sharp contacts. The entire mineralogic similarity of this second type to the pegmatite which grades into the granite leads to the belief that the two types are genetically connected and that the intrusion of the pegmatite masses that show sharp boundaries followed quickly on the solidification of the granite which they cut.

Very similar relations were observed at the Grant quarry, about 1½ miles east of Hillside and 3 miles west of Brunswick. This quarry has been described by Dale.[a]

The relations between the pegmatite and foliated rocks, which are probably of igneous origin, is well exhibited in Brunswick village at a quarry for road materials near the Lewiston branch of the Maine Central Railroad. The folia in the rocks are in many places very straight and regular for considerable distances. Much of the rock is a light-gray schist which has the mineral composition of a hornblende granite.

The slide of this rock examined shows an interlocking granular texture in which most of the grains range from 0.15 to 0.60 milli-

[a] Dale, T. N., The granites of Maine: Bull. U. S. Geol. Survey No. 313, 1907, p. 76.

meter. It is composed of about two-fifths quartz, two-fifths feldspar, and one-fifth hornblende, with subordinate titanite and biotite. Some of the hornblende crystals are 1.2 millimeters in length. Their tendency to parallel elongation and to greater abundance in some layers than in others gives the rock its schistose character. Biotite is also most abundant in the layers that are most hornblendic. The feldspar is principally orthoclase with a little microcline and plagioclase near andesine. Many of the quartz grains show strain shadows, but there is no other evidence of dynamic action.

Alternating with this rock are bands of very dark gray to nearly black hornblende-biotite schist with lustrous cleavage faces. An intermediate phase is a dark-gray hornblende schist with a few narrow quartz bands up to about one-eighth inch across.

Under the microscope this rock is seen to consist of quartz, plagioclase, and hornblende. The plagioclase is andesine and is about equal to hornblende in abundance. Quartz is slightly less abundant than either. Titanite is subordinate. Occasional narrow bands are more coarsely crystalline and are largely quartz, with some feldspar. Their grains interlock intimately with those of the finer portions of the rock. The schistosity, as in the more acidic bands, is due to the concentration of hornblende along certain planes and of quartz along certain others and to parallel elongation of many of the hornblende crystals.

If these schists represent original sediments their recrystallization has been so complete as to obliterate all traces of such an origin. The abundance of feldspar, on the other hand, especially in the more basic bands, renders it much more probable that they are primary or flow schists.

The pegmatite in some cases is in sharp contact with the gneiss, and the contacts may parallel or cut across the foliation. In other cases the pegmatite seems to grade into the gneiss with such completeness as to indicate either that portions of the gneiss were not yet completely solidified when the pegmatite was intruded or that the pegmatite produced locally very complete recrystallization in the schist. The pegmatite is a typical biotite pegmatite showing much graphic granite and a few crystals of pure feldspar 4 or 5 inches across.

WESTBROOK.

A quartz deposit which was worked to a small extent many years ago is located about 1 mile northwest of the village of Cumberland Mills. The quartz forms part of a pegmatite dike intruding mica schist and granodiorite. The width of the dike varies from 2 to 10 feet, and its trend is nearly north and south. Most of the mass is typical granite-pegmatite of moderate coarseness, but with this is associated a body of nearly pure white quartz, which in places seems intrusive in the pegmatite, though elsewhere passing gradually into it. The quartz quarried was taken to Portland and there ground for use in pottery and filters.

HANCOCK COUNTY.

Pegmatite is present only in relatively minor amounts in association with the granites of Hancock County. The occurrence of molybdenite with pegmatite at Catherine Hill, near Tunk Pond, has been described by Emmons.[a]

LINCOLN COUNTY.

EDGECOMB.

The rocks of the town of Edgecomb are mainly quartz-mica schists of sedimentary origin which have been intruded by pegmatite, granite, and minor amounts of granite gneiss. The pegmatites have been exploited for feldspar at one locality near the center of the town.

Edgecomb feldspar quarry.—A feldspar quarry, long since abandoned, is situated 2¼ miles south of the village of Newcastle and about one-half mile south of the road extending from North Edgecomb to Briar Cove, on Damariscotta River. It is within the Boothbay quadrangle of the United States Geological Survey.

The locality was visited by the writer in August, 1906. The excavations consist of two open pits, one 150 feet long and 50 feet wide, filled with water at the time of the writer's visit; the other 50 feet long, 25 feet wide, and 15 feet deep. The soil overburden is slight. The pegmatite resembles in its mineral character that quarried at Topsham, in Sagadahoc County, but contains less feldspar of commercial grade.

The quartz is not abundant enough to be of commercial importance. The largest masses observed are between the two pits and are 3 feet across. The color varies from white to dark gray.

The feldspar is buff to cream-colored orthoclase and microcline, occurring principally in graphic intergrowth with quartz. At the northwest end of the larger pit some masses of nearly pure feldspar are 3 feet across, but such size is quite exceptional.

Biotite in the usual lath-shaped crystals, in places attaining a length of 3 feet, is very abundant and is the most injurious of the mineral constituents, black tourmaline being wholly absent so far as observed.

Pink opaque garnets occur locally but are not abundant. Many of them are inclosed by muscovite.

As far as could be observed, very little feldspar of a quality suitable for the pottery trade remains at this locality, the prevalence of

[a] Emmons, W. H., Ore deposits of Maine and the Milan mine, New Hampshire: Bull. U. S. Geol. Survey No. 432, 1910, p. 42.

biotite rendering most of the material worthless for that purpose. The water in the larger pit of course prevented its thorough examination. An examination of the vicinity yielded no information as to the trend or extent of the deposit, and showed no other masses of commercially valuable feldspar. No gem minerals have been reported, and there are no indications, such as the occurrence of pockets, lepidolite, black tourmaline, etc., that any are likely to be found. Under present commercial conditions, the deposit may be regarded as worked out. It may in the future be of value if some commercially practical method of separating the mica can be devised, or it may be used for purposes where the presence of black mica (biotite) is not detrimental, such as for fertilizing, poultry grit, ready roofing, etc.

Geologic relations.—About half a mile north of the Edgecomb feldspar quarry, on the north side of the road, the predominant rock is a medium-grained granite of slightly varying texture, which along certain bands and in some irregular patches is pegmatitic. The constituents of the granite are identical with those of the pegmatite and there can be no question that the two rocks solidified from the same parent magma at about the same time. Muscovite is almost entirely absent from this granite, as it is from the pegmatite of the above-described feldspar quarry, biotite being the dominant mica. West of these granite outcrops extensive ledges of pegmatite intrude quartz-mica schists in a very irregular manner, at many places cutting sharply across their foliation.

Typical structural relations between the pegmatite and the schists are well shown along the north shore of the narrow gurnet known as the Oven Mouth. Here the schists are traversed by numerous small pegmatite intrusions, most of which are parallel to the schist folia or cut them at low angles only.

The smaller pegmatite intrusions commonly assume the form of a series of connecting lenticles or show periodic swellings along their lengths. The schists are dark gray to purplish and show quartz, biotite, and hornblende as their dominant constituents, with muscovite and garnet as accessories. Feldspar was not observed and if present at all is very meager in amount. The schists are almost certainly of sedimentary origin.

BOOTHBAY HARBOR.

Character and relations of the pegmatite.—The rocks of the town of Boothbay Harbor are largely quartz-mica schists which are intruded and in many places intimately injected by granite and pegmatite. Two occurrences of the very unusual rock prowersose were also observed. Very excellent and instructive exposures occur along the irregular shore line of this region, and although none of the pegmatites have proved commercially valuable their geologic relations at a number of points are of much scientific interest.

Excellent exposures on the first point west of Boothbay Harbor village show the intrusive pegmatite and the intruded quartz-biotite schists locally very much contorted, much as if the two had been stirred up together with a gigantic spoon. In most places, however, the schist is of fairly uniform trend over considerable areas. Other exposures just west of these show a number of schist fragments inclosed by the pegmatite. The fragments are subangular, but at their extremities tail out somewhat into the pegmatite. The fragments as a whole appear therefore to have maintained their rigidity but to have yielded somewhat about their borders to the deforming action of the intrusive pegmatite.

On the shore of McKown Point about one-fourth mile south of the United States fish hatcheries pegmatite and granite are intrusive into quartz-mica schists. The contact between the schist and the igneous rocks is sharp, neither rock showing any notable changes in grain or texture as the contact is approached. The transition from pegmatite to granite is also abrupt, although crystallographic continuity is preserved. It is impossible to say which is the intruded and which the intrusive rock, and their association is extremely irregular. The granite shows distinct flow lines parallel in a general way to the schist walls and particularly well developed next the pegmatite. The latter also shows a tendency toward the development of faint flow lines next the granite, these being defined by a concentration of biotite plates along certain planes.

The granite gneiss is dark buff to gray and shows a rather faint foliation due to the aggregation of the biotite along certain planes or lenses few of which are continuous for more than one-half or three-fourths of an inch. The interspaces are largely quartz and feldspar. Under the microscope the mineral constituents in order of abundance are seen to be quartz $>$ orthoclase and microcline $>$ or $=$ oligoclase $>$ biotite $>$ muscovite. Orthoclase is greatly in excess of microcline and occurs in larger grains. The average size of grain is about 1 millimeter, though a few feldspars are 2 millimeters across. The rock is very fresh, though some of the feldspars show a slight clouding with decomposition products. No parallel structure is observable under the microscope. There is complete interlocking of the grains, which show no important amount of fracturing, no crushed borders, nor any other evidence of dynamic action. The foliation appears to be an original feature developed by flowage before complete solidification.

The pegmatite associated with the gneiss shows light-gray quartz and gray to buff feldspars in nearly equal amounts, with biotite the dominant mica, as in the gneissic granite. The texture is wholly irregular and typically pegmatitic because of the great range in size exhibited by crystal grains of the same mineral species. Quartz is the most abundant mineral with microcline > oligoclase > biotite > or = orthoclase > muscovite. The rock differs from the associated gneissic granite mainly in its texture and in the fact that microcline dominates over orthoclase instead of bearing the reverse relation to it.

The close association of the granite and pegmatite and the fact that the same minerals are present in the same order of abundance in both rocks is highly suggestive of a genetic connection between the two.

At a point on the east shore of Boothbay Harbor the fine-grained pegmatite was observed to be traversed by a vein of white quartz 2 to 3 inches in width. The borders of this vein are not sharp; feldspar crystals of the bordering pegmatite project into it, and in some instances their inner borders (next the quartz) show well-developed crystal faces. Isolated crystals of feldspar up to 3 inches in length also occur, apparently wholly surrounded by the quartz of the vein. The feldspathic character of this vein and the absence of a sharp or straight boundary between it and the pegmatite indicate that it was not deposited as a fissure filling along a fracture plane traversing solid pegmatite, but rather that it was genetically a part of the pegmatite magma and was formed before the complete solidification of its host. Apparently it represents an end product of the pegmatite crystallization. The sheetlike form of the vein indicates presumably that the pegmatite was sufficiently rigid to permit the formation of a rift of some sort along which the more quartzose magma could penetrate, but that coarsely interlocking crystallization between vein and wall was still possible. Similar relationships have been observed by the writer on a larger scale in some of the feldspar quarries of Connecticut. (See Pl. XVI, *B*, p. 18.) They are of importance as showing without much question that many at least of the quartz veins associated with the pegmatites may be regarded as an end product of the crystallization of the pegmatite magma.

Southward along the east shore of Boothbay Harbor to Spruce Point abundant dikes of pegmatite are found traversing the schists; they vary from one-fourth to one-half an inch to 10 feet or even 50 feet across. Nearly all of the dikes and particularly the smaller ones assume the form of a succession of connecting lenses, indicating a very uneven penetration of the pegmatite magma between the schist folia. The schists usually exhibit a thickening of their laminæ opposite the "nodes" of these irregularly bulging dikes, indicating a crystallographic rearrangement of the schist constituents as an accompaniment of the pegmatite intrusion.

It is significant that numerous dikes of granite also exposed along this shore never exhibit such irregular swelling and thinning, but are nearly parallel-walled even where intruded parallel to the foliation of the bordering schists.

On the point due north of Cabbage Island the rocks are almost entirely granite and pegmatite associated in a very irregular manner. The pegmatite forms dikes of varying width and irregular boundaries in the granite and also forms narrow stringers and wholly irregular patches. In general the change from one rock to the other is rather abrupt, although characterized by complete crystallographic continuity. In the places where the association is most intimate and irregular it is difficult to see how the granite could have been wholly solidified at the time of the pegmatite crystallization.

The granite is gray to pinkish, with a faint local foliation. The average size of grains is about one-half to three-fourths of a millimeter. The texture is typically granitic with quartz > orthoclase and microcline > oligoclase > biotite > muscovite. The quartz shows undulatory extinctions. Some of the smaller quartz crystals are inclosed by orthoclase or oligoclase and show rounded outlines. Some of the quartz also crystallized earlier than or contemporaneously with the biotite crystallization. The bulk of the quartz, characterized by more irregular outlines and larger grains, is a later crystallization than the biotite and appears to be about contemporaneous with the feldspars. Among the feldspars orthoclase is present in greater abundance and larger grains than microcline. Oligoclase is almost equal to the potash feldspar in abundance. Many of the feldspar crystals inclose small crystals of muscovite, which are apparently original. Some micrographic intergrowths of feldspar and quartz occur.

The pegmatite is characterized by the same minerals as the granite. Quartz is the dominant constituent, with orthoclase and microcline second and oligoclase third. Biotite dominates over muscovite, but is less abundant than in the granite. The quartz exhibits little or no undulatory extinction. Some of the grains exhibit crystal outlines on certain sides, but the outlines of others are very irregular. The feldspars exhibit only slight decomposition.

It is notable that both rocks carry the same minerals in the same order of abundance.

In general the pegmatite characteristic of the Boothbay Harbor region shows considerable uniformity in mineralogical make-up. Characteristically it shows irregular crystals of orthoclase-microcline, ranging in diameter up to 6 inches, surrounded by a less coarsely crystalline association of potash feldspar, white to gray or amber-colored quartz in masses sometimes several inches across, small amounts of nearlv white plagioclase, and varying proportions of muscovite and biotite in crystals seldom over an inch across, usually more or less aggregated in bunches. Red garnets are present in varying but small numbers and are rarely over one-fourth inch in diameter. Small amounts of a white sugary matrix are not uncommon and consist largely of a fine graphic intergrowth of quartz and feldspar.

Schist associated with pegmatites.—A specimen of schist collected along the shore near the United States fish hatcheries on McKown Point illustrates the indeterminate character of some of the foliates associated with the pegmatite. The rock is dark-gray, millimeter grained, with a fairly perfect foliation due mainly to parallel orientation of the mineral grains but accentuated by quartz laminæ 1 to 2 millimeters across.

Under the microscope the texture is seen to be interlocking granular, the constituents being quartz > hornblende > labradorite, with biotite, titanite, calcite, and apatite subordinate. Mineralogically the rock is therefore a quartz-rich diorite. Many of the quartzes extinguish abruptly, though some show slight undulatory extinction. The green hornblende grains are very irregular, but show a tendency towards elongation in a parallel direction. This elongate character, together with the tendency toward aggregation of the quartz grains along certain lines, produces the foliated structure. Titanite is very abundant in irregular grains and also in grains showing elongate rhombic outlines. The hornblende shows no alteration whatever. The feldspar is in part perfectly fresh but some of the grains show saussuritization.

Calcite, which is present in moderate amounts, is in contact with quartz, titanite, or unaltered feldspar or hornblende, the contacts being as sharp as between any others of the rock constituents. Its abundance is scarcely explainable by the very slight alteration characteristic of most of the rock, and it is necessary to assume either that it completely replaced certain grains or portions of grains of other minerals, without any of the mottling and irregular penetration usually characteristic of such replacement, or else to assume that it crystallized at the same period as the quartz, feldspar, hornblende, etc., with which it is in contact. Such an association could readily be explained as the result of contact or regional metamorphism of a slightly calcareous arkose. The texture and mineral composition and even the presence of calcite is not, however, incompatible with an igneous rather than a metamorphic-sedimentary origin.

We are accustomed to reason by analogy from the phenomenon of calcining observed when carbonates are heated under ordinary surface conditions to the postulate that carbonates, if they existed in igneous rocks, would undergo the same changes, and thence to conclude that carbonates can not exist as such in igneous rocks.

The reasoning is obviously weak, because in the one case the conditions are those of low pressure and ready escape of gases, whereas in the case of a magma cooling to form a granular rock of moderate coarseness they are probably those of relatively high pressure and much greater ability to retain components which under surface conditions would be freed in a gaseous form. The microscopic evidence of the original character of the carbonate in this case is regarded as suggestive rather than conclusive, but there appears to be no a priori reason why it should not be original.

The schist described lies between two intrusions of pegmatite, one 5 to 6 feet wide and the other 4 to 5 feet. The field and microscopic evidence is insufficient to determine whether it is igneous or metamorphic-sedimentary in origin, and because of the abundance of plagioclase it is doubtful whether a chemical analysis would furnish conclusive evidence.

Schists of the Boothbay Harbor region which she believes to be of metamorphic-sedimentary origin have been described and analyses given by Dr. Ida H. Ogilvie.[a]

Syenite porphyry.—In 1906 the writer described[b] a rock of peculiar appearance and unusual composition from the town of Appleton in Knox County. The rock is a porphyry showing blue-gray phenocrysts of potash feldspar up to 1½ inches in length in a dark-green groundmass composed mainly of biotite and hornblende with minor amounts of titanite, apatite, quartz, magnetite, and albite. Chemically it is unusual because of the great dominance of potash over soda in a rock so femic and so high in lime.

Rocks which in the field are indistinguishable from prowersose from the Appleton locality and which on chemical analysis fall in very closely related divisions of the quantitative system of rock classification, from several localities in the Boothbay Harbor region, have been described by Dr. Ida H. Ogilvie.[c]

A number of Dr. Ogilvie's localities were visited by the writer before he became familiar with her published descriptions. A locality not specifically mentioned by her is the shore of Linekin Bay, southeast of Mount Pisgah. At this locality and on Spruce Point the syenite is intruded by dikes of pegmatite and of fine-grained granite. Many central portions of the syenite intrusions show little or no foliation and a very heterogeneous orientation of the phenocrysts, but in the narrower masses or near the borders of the larger masses foliation is well developed, and is found to be due to crushing and shearing movements, probably accompanying

[a] Ogilvie, I. H., A contribution to the geology of southern Maine: Ann. New York Acad. Sci., vol. 17, pt. 2, 1907, pp. 526-527.

[b] Bastin, E. S., Some unusual rocks from Maine: Jour. Geology, vol. 14, 1906, pp. 173-180.

[c] Ogilvie, I. H., A contribution to the geology of southern Maine: Ann. New York Acad. Sci., vol. 17, pt. 2, 1907, pp. 536-541.

dynamic metamorphism. On Spruce Point many of the feldspar phenocrysts are nearly black on account of the abundance of minute inclusions.

OXFORD COUNTY.

ALBANY.

The rocks of most of the town of Albany are quartz-mica schists of probable sedimentary origin which have been intensely injected by pegmatite and intruded by dikes of fine-grained granite. In all observed places where the granite and pegmatite were associated, the former was the older rock. Along the road running nearly parallel to Crooked River, near the center of the town, diorite or quartz diabase is of abundant occurrence and is intruded by dikes of fine diabase, fine-grained granite containing few dark-colored minerals, and pegmatite. In the northwestern part of the town a gray granite gneiss forms the country rock over large areas.

French Mountain beryl locality.—In the eastern part of the town of Albany a pegmatite mass very rich in quartz has yielded some beryls of fine gem quality. The locality is in the woods in a sag between two knobs of the hill crest and is difficult to discover without a guide. Only a few blasts have been made in the ledge. Much of the quartz is very clear and some is of a fine rose tint. The locality is of interest to the mineral collector but is not of commercial importance.

Bennett mica prospect.—A small mass of pegmatite which has been prospected for mica by W. S. Robinson is situated in the western part of the town of Albany on the farm of F. H. Bennett, about 5 miles west of Hunt Corners. The pegmatite dike has an exposed thickness of 10 feet and is intrusive in granite gneiss similar to that occurring farther west. The pegmatite is a coarse association of quartz, muscovite, orthoclase, and black tourmaline. The muscovite occurs in graphic intergrowth with quartz and also in "books" up to 6 inches across, though mostly under 3 inches. Nearly all is of the wedge variety and shows twinning. Feldspar is too intimately mixed with black tourmaline to be of any value. Neither the quantity nor the quality of the materials here seem to warrant further development.

Pingree mica prospect.—Another pegmatite mass, situated on the farm of C. P. Pingree, in the extreme western part of the town of Albany, was worked to a slight extent for mica in 1878–79, and was opened again in 1900 by W. S. Robinson; no shipments, however, except of samples, have ever been made. The ledge has yielded some beryls of gem quality. In the absence of the owner of this property the writer was unable to visit it. Bethel, the nearest station, is about 8 miles distant on the Grand Trunk Railway.

ANDOVER.

F. G. Hillman, of New Bedford, Mass., has reported his discovery in pegmatite in Andover of lilac-colored spodumene, or kunzite, as well as of some with a greenish color. A cleavage specimen sent to the Survey measured about 12 by 10 by 3½ millimeters and had a very pretty clear pink color. It was not entirely without cleavage cracks, however. The greenish material was a pale aquamarine, nearly clear, though rather badly fractured. This spodumene was obtained near the surface, and excavating to a greater depth has disclosed no material of gem quality.

BUCKFIELD.

The rocks of the town of Buckfield are largely quartz-mica schists which have been injected by pegmatite. The pegmatites have not been extensively worked in any part of the town but have at a few places yielded golden beryl, aquamarine, and cæsium beryl. A fine twinned crystal of chrysoberyl from this town in the museum of the Sheffield Scientific School of Yale University is 2 inches long and one-half inch thick. This same collection also contains very perfect diamond-shaped crystals of muscovite from Buckfield.

GREENWOOD.

So far as known the rocks of the southern part of the town of Greenwood are schists which have been intruded by granite and pegmatite. In the northern part of the town granite is believed to become more abundant.

A small abandoned mine which has yielded many interesting mineral specimens and some gem tourmalines is situated about three-fourths of a mile east of Hicks Pond in the southern part of the town. The pit, which is 15 feet in width and about 25 feet long, is located on the western slope of a steep forested hillside, near its summit. It was visited by the writer in September, 1906.

The rock is a coarse pegmatite made up largely of quartz, muscovite, albite of the clevelandite variety, and some orthoclase-microcline. The feldspar does not occur in commercial amounts. Some of the muscovite books are 14 inches across the plates and a foot in thickness, but all except a few show twinning and wedge structure, which render them useless as a source of plate mica. In places mica constitutes half of the rock. Black tourmaline is present but is not abundant.

Pockets are numerous, most of those observed being under 1 foot in diameter. One gigantic one was 7 feet wide and 10 feet long, with a depth of at least 4 feet, the floor being buried under a considerable thickness of detritus; numerous small lobes add irregularity to its form. Wherever the walls of this pocket have not "shelled off" by the action of frost, etc., they are covered with a coating of minute crystals of quartz. In some places the minerals which have been coated in this way have subsequently decayed, leaving only their quartz covering. As these quartz crystals are transparent and usually show hexagonal forms they probably crystallized below 575° C., presumably as a deposition from meteoric waters. Where this secondary quartz has been deposited on original quartz crystals it has grown in perfect crystal continuity with them but is distinguished by being opaque white rather than transparent. It is interesting to note that this growth of secondary quartz has been most rapid at the apices of the quartz crystals, the coating here being much thicker than on the sides of the crystals.

The precise form and extent of the pegmatite deposit could not be ascertained, but it appears to be irregular. The coarse pegmatite is traceable for about 25 feet north of the present pit, beyond which it is concealed by soil. The southern wall of the pit is composed of schists, which strike N. 50° W. and dip nearly vertical.

The locality has yielded a considerable number of tourmalines of gem quality, but very few have been marketed, much of the material being still in the hands of George Noyes, of Fryeburg, who developed the property. Other minerals occurring here are apatite in small, opaque, olive-green crystals (present in great abundance in some of the fine-grained parts of the pegmatite), opaque, pale lilac-colored spodumene, cassiterite, beryl, herderite,[a] zircon, and phenacite.

The locality, though affording many interesting mineral specimens, can not be regarded as of much commercial importance.

HEBRON.

The rocks of the town of Hebron are principally quartz-mica schists, extensively intruded and injected by pegmatite, which shows great variations in coarseness. The coarser phases have proved of economic importance for feldspar at Number Four Hill in the western part of the town and on the Hibbs farm north of Hebron village, and gem tourmalines and various mineral specimens have been obtained at Mount Rubellite, about 2 miles northeast of Hebron village.

Hibbs feldspar and mica mine.—A small feldspar and mica mine was opened in 1906, about 1½ miles north of Hebron village near the Buckfield road. It is located on the farm of Alton Hibbs and was operated during 1906 by J. A. Gerry, of Mechanic Falls, and W. Scott Robinson. It was abandoned in 1907. The property was visited by the writer in August, 1906, after considerable stripping and prospecting had been done. The ledge was exposed for a distance of 300 to 350 feet along the southwest side of a small creek valley, the

[a] Described by S. L. Penfield, Am. Jour. Sci., 3d ser., vol. 47, 1894, p. 337.

average width of outcrop being about 30 feet, though increasing to 50 feet at at least one point; only shallow excavations had been made. The exposures show numerous masses of pure orthoclase-microcline feldspar 2 to 3 feet across, associated with much graphic granite. The spar is mottled buff to blue-gray. Small amounts of the soda feldspar, albite, are found. The principal iron-bearing impurity is black tourmaline, so aggregated that it can be readily separated in the mining. It was estimated that feldspar of commercial grade for pottery purposes formed about 60 per cent of the rock mined. Biotite is present in the usual lath-shaped crystals up to 1 foot wide and 3 feet long but is not at all abundant.

Muscovite is found in most parts of the pegmatite in small books up to 2 to 3 inches across; but it occurs in abundance and in larger plates only at the southwestern border of the mass, where in a zone averaging 3 to 4 feet in width the mica books average 5 inches in diameter and one reaches 30 inches; this specimen, however, was imperfect. It is estimated that in this zone muscovite constitutes on the average at least 10 per cent and sometimes 20 per cent of the rock. Of this it was estimated that fully 60 per cent could be trimmed into plates, the remainder being usable only as scrap mica. Wedge structure and ruling are the common defects. Plates as large as 5 by 6 inches could be trimmed from a few of the mica books.

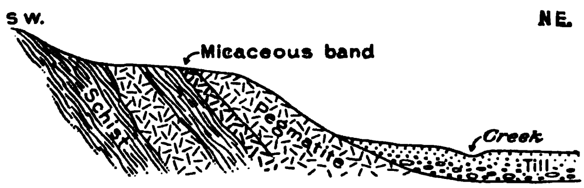


FIGURE 6.—Relations of pegmatite and wall rock at Hibbs feldspar and mica mine, Hebron.

Exposures are not numerous enough to reveal the full form or extent of the pegmatite mass. On its southwest side it is bounded by quartz-mica schists, which trend from N. 30° W. to N. 50° W., averaging about N. 45° W., and apparently dip about 45° NE. The northeast border of the deposit is wholly obscured by drift. The mica-rich band which follows the southwest margin of the pegmatite mass can be traced for 300 to 350 feet—nearly the whole distance through which the pegmatite mass itself is exposed. The apparent relations of the pegmatite and schist are shown in figure 6.

From the exposures at the time of the writer's visit this property was regarded as a promising one for both feldspar and mica mining. It seems probable that further stripping will show that the deposit extends northwest and southeast of the present exposures, and since it seems to be steeply inclined there is no reason why it should not persist in good quality to considerable depth. The development work was suspended for reasons wholly aside from the quality of the deposit. All output must be hauled by teams 3 miles to Hebron station, on the Rangeley division of the Maine Central Railroad.

Mount Rubellite.—A hill known as Mount Rubellite, situated about 2 miles northeast of Hebron village, was formerly worked to a slight extent for its gems and rarer minerals by Augustus Hamlin, of Bangor, and Loren B. Merrill, of Paris. The writer's visit was made in August, 1906.

The small opening exposes a face of rock about 5 feet high and 35 feet long on a southwestward sloping hillside. The pegmatite resembles in a general way that at Mount Mica (p. 86), but has yielded few pockets, Mr. Merrill reporting the occurrence of only three or four, one of which was about 3 feet wide, 6 feet long, and 18 inches deep. Buff-colored orthoclase-microcline feldspar is in many places so penetrated by black tourmaline, the principal iron-bearing impurity, as to be useless for pottery purposes, but a few pure masses 5 feet across indicate that the locality may be worth working. At one place books of mica, some of them 5 to 6 inches across, but mostly smaller, show on the surface of the unopened ledge above the pit, but they do not seem to form a definite vein. Probably some of this mica could be marketed in connection with the feldspar, but the indications do not warrant development for the mica alone.

Colored tourmalines have been found at this locality, but for the most part in the solid pegmatite rather than in pockets, so that their excavation without shattering was not practicable. As may be inferred from the name given to the locality, the pink or rubellite variety was of common occurrence.

Other minerals from this locality are ambylgonite, apatite in small opaque green crystals, arsenopyrite, beryl, cassiterite inclosed in clevelandite, childrenite, cookeite, damourite (an alteration product of tourmaline), halloysite, herderite,[a] lepidolite,[b] pollucite[c] (embedded in the "sand" at the bottom of two pockets), and vesuvianite.

The trend or extent of the coarse pegmatite could not be determined.

It is possible that it would pay to work this locality for its feldspar, mica, and occasional gems, but it would probably be unprofitable to work it for any one of these alone. The haul to Hebron station, on the Rangeley branch of the Maine Central Railroad, is about 3 miles.

Streaked Mountain.—Streaked Mountain, in the extreme northwest corner of the town of Hebron, shows in a striking way the large size which some of the masses of coarse pegmatite may assume. The

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[a] Wells, H. L., and Penfield, S. L., Am. Jour. Sci., 3d ser., vol. 44, pp. 114-116, 1892, also 3d ser., vol. 47, p. 333, 1894.

[b] Clarke, F. W., Bull. U. S. Geol. Survey No. 42, 1887, p. 14.

[c] Wells, H. L., On the composition of pollucite and its occurrence at Hebron, Me.: Am. Jour. Sci., 3d ser., vol. 41, 1891, pp. 213-220.

crest of this mountain trends in a northwest-southeast direction and was examined for over half a mile of its length. The width of outcrop examined from southwest to northeast across the trend of the ridge was also about half a mile. The whole area traversed and the remainder of the mountain so far as it could be seen was underlain almost exclusively by coarse pegmatite, the mountain being essentially a "boss" of this material. Near the highest part a few patches of schist a few square yards in surface are entirely surrounded by pegmatite. Another schist mass was 40 to 50 feet wide and 100 feet long. It was bordered on three sides by pegmatite, its fourth contact being obscured by vegetation. These masses appear to be entirely unconnected with any large schist areas.

The pegmatite is of the usual type, being an association, often in graphic intergrowth, of quartz, orthoclase-microcline, muscovite, black tourmaline, and subordinate amounts of biotite. In a few places, as on the highest part of the mountain, it is coarse enough to yield feldspar of suitable quality for pottery purposes, some masses of pure potash feldspar being 2 to 3 feet across and rather coarse graphic granite being abundant. Its inaccessible location would, however, render its working impracticable under present conditions. Certain portions of this pegmatite consist almost wholly of graphic granite, intersected by blades of muscovite, but these areas grade into others characterized by a granular-pegmatitic texture and containing the same minerals, but also much black tourmaline and some garnet.

It is difficult to conceive of a mass of this size and general uniformity crystallizing under anything like vein conditions. With high gaseous content and hence high mobility it would be natural to expect more differentiation both in texture and composition. Although the composition of the pegmatite magma was probably slightly different from the normal granite magma, it seems probable that the rigidity of the mass was not greatly less than that which would characterize a granite boss of similar dimensions.

Mills feldspar quarry.—A small abandoned feldspar quarry, situated on Number Four Hill, near the Paris–Hebron line, was visited by the writer in August, 1906. The quarry was worked by the Mount Marie Mining Company in 1901 but was soon abandoned.

The principal pit is about 75 feet long by 30 feet wide and 10 feet in maximum depth. A second pit close by is about 30 by 30 feet and 10 feet deep.

The bulk of the feldspar belongs to the potash varieties, orthoclase, and microcline, though some albite of the clevelandite variety occurs in the coarser-grained portions. In the northwestern part of the larger pit some masses of pure spar are 3 to 4 feet across. The bare ledge to the north of the smaller pit for a length of 40 or 50 feet and a width of about 30 feet shows feldspar in crystals 2 to 4 feet across but containing numerous small crystals of black tourmaline. In the larger pit there is a small amount of feldspar of commercial grade at its northwest end, but in the smaller pit and in the unopened ledge near the pits black tourmaline is so intimately and abundantly associated with the feldspar as to render most of the latter valueless for pottery purposes under present commercial conditions. The coarsest and most highly feldspathic portion of the deposit as exposed in the larger pit contains some clevelandite and granular lepidolite and a few colored tourmalines of pink and green tints, which are translucent to opaque. A few small pockets occur and several less than a foot in diameter were exposed at the time of the writer's visit. In some of the pockets a few transparent tourmalines of gem quality were found during the mining operations. South of the workings the ledge shows very little feldspar of pottery grade and within 200 feet there begins to be some admixture of schist with the pegmatite.

Muscovite has been saved during the mining, but most of it is what is known as wedge mica and would be valueless except as a source of ground mica. Biotite or black mica is very rare, black tourmaline being the principal iron-bearing impurity.

The trend and exact limits of this deposit could not be determined, but there is every indication that the supply of feldspar suitable for use in the pottery trade is very small, most of the material showing too great an abundance of black tourmaline. An examination of the whole coast of the hill south of the pits showed no spar or other minerals of commercial grade. Even if the mica and tourmalines were marketed as accessories it is probable the deposit could not be made to pay.

No mining machinery was installed at this locality. The feldspar was hauled 5 miles, mostly down grade, to South Paris, on the Grand Trunk Railway. Only a few tons of it was shipped, and much spar now lies in stock piles at the quarry.

NEWRY.

The rocks of Newry were studied only in the extreme northeast corner of the town at a quarry formerly operated for gem tourmalines.

The Dunton tourmaline mine is situated near the summit of a considerable hill that rises back of the farm of Joshua Abbott, about 1 to 1½ miles west of the wagon road between North Rumford and South Andover. It was operated in the summers of 1903 and 1904 by H. C. Dunton, of Rumford Falls.

The pegmatite mass appears to be sill-like in form, with an average thickness of about 20 feet and a dip of about 40° SE. The wall rock has been intensely altered, but whether this is largely due to contact metamorphism by the pegmatite is uncertain. It is a light-green rock, exceedingly tough, and is composed largely of muscovite, actinolite, and quartz, with a little acidic plagioclase. The mineral grains interlock with no trace of schistose structure.

The higher slopes of the mountain between the mine and the wagon road show much pegmatite, but the lower slopes near the road are principally a quartz-mica schist, which is shown by locally recognizable bedding planes to be of sedimentary origin.

The pegmatite mass is of exceedingly coarse texture, and the principal minerals are quartz, orthoclase-microcline, muscovite, bladed albite (clevelandite), spodumene, lepidolite, and tourmaline, with beryl, columbite, and autunite as minor constituents.

The quartz and orthoclase-microcline are commonly in graphic intergrowth, as are also quartz and muscovite. Orthoclase is the dominant feldspar in most parts of the pegmatite mass. The muscovite is not of commercial quality, defects of twinning, wedge structure, and A structure being common. Many muscovite plates inclose crystals of transparent green tourmaline, some of those observed being one-fourth inch wide and 2 to 3 inches long. None are large enough or perfect enough to yield gems.

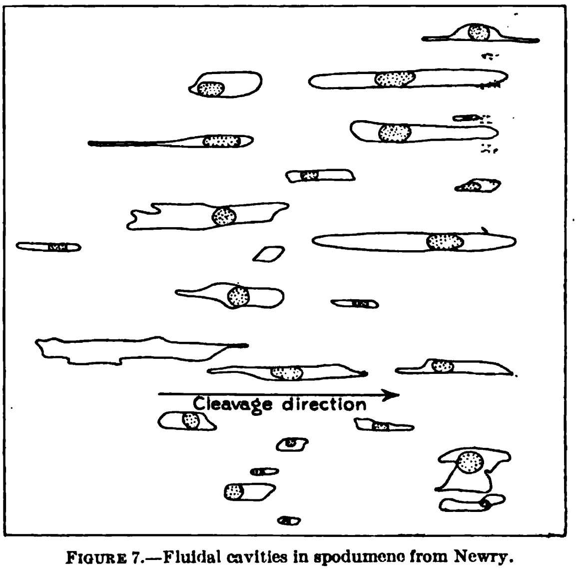

FIGURE 7.—Fluidal cavities in spodumene from Newry.

The central 5 or 6 feet of the sill-like mass of pegmatite constitutes the gem-bearing zone and is characterized by a different mineral association. Quartz, orthoclase-microcline, and muscovite occur, but clevelandite is locally more abundant than potash feldspar; some of its bladelike crystals are 10 to 12 inches in length. With it is closely associated lepidolite, usually in small aggregates, but occasionally in large masses; one mass measured 6 by 2 by 3 feet but inclosed some clevelandite and pink tourmaline. The lepidolite, as at most of the gem localities, forms granular aggregates of minute plates and prisms. Spodumene occurs in flat crystals, some of which are 2½ feet in length; it is opaque and mostly white, though pale pink tints are sometimes found. Elongate fluid inclusions, nearly all of which are elongate parallel to the principal cleavage and contain vacuoles, are abundant in this spodumene; their size and shape are shown in figure 7.

Most of the tourmaline is an opaque dark blue-green, though some is nearly black. Association of this variety with the clevelandite is particularly common. Other tourmalines of lighter color are also abundant, particularly varieties characterized by pink centers surrounded by borders of light grass green. Some of these crystals are transparent in part and have yielded gem material, but they are inclosed in the solid pegmatite and are difficult to remove without shattering. Some of the pink and green tourmalines are of large size, one being reported as 4 to 5 inches across and about 2 feet long; the larger ones, however, are not of gem transparency. So far as known no pockets have been encountered.

Beryl was not seen in place, but a small loose crystal, though flawed, was perfectly transparent and almost deep enough in color to be classed as emerald. Autunite occurs in crystals, few of them over one-sixteenth of an inch across, embedded in or lying between plates of clevelandite. Most of it has wholly decomposed, leaving a small cavity and a canary-yellow stain in the surrounding feldspar.

The locality was abandoned because the tourmalines could not for the most part be removed from the ledge without being shattered so much as to destroy their gem value. If further excavation should reveal the presence of pockets in this pegmatite, some of these would almost certainly contain gem tourmalines which could be excavated by careful mining. In view of the fact that no pockets have yet been found it seems rather doubtful if further excavation will reveal any.

NORWAY.

The rocks of the town of Norway are largely quartz-mica schists intimately injected by pegmatite. No commercially important pegmatite deposits are known to occur, but some localities are of interest to the mineral collector.

At Tubbs Ledge, 2 miles northwest of Norway village, a pegmatite mass which has been blasted at several localities in a pasture shows orthoclase, white quartz, rose quartz, clevelandite, black and green tourmalines, and lepidolite, the latter a granular aggregate of unusually small plates. The presence of lepidolite, colored tourmalines, and clevelandite shows that the locality is a favorable one for further prospecting for gem tourmalines.

In the northeast corner of the town near Cobble Hill and near the road corners due southwest of West Paris a pegmatite ledge opened by George Howe, of Norway, has yielded small but perfect crystals of chrysoberyl, zinc spinel, and zircon. The pegmatite containing these minerals shows distinct evidence in a somewhat schistose structure and slickensided talcose surfaces of some movement since solidification. The chrysoberyl is clearly an original constituent, but the minute zircons one-sixteenth to one-eighth inch in length lie upon the talcose slickensided surfaces and were probably formed during the shearing process.

Two dikes, cutting pegmatite of moderate coarseness in a roadside exposure in the eastern part of Norway, are instructive. One dike, ranging from 6 inches to 3 feet in width, is a coarse aggregate of quartz (some rose colored), feldspar, muscovite, and black tourmaline; it is not separated from the wall rock by sharp boundaries. The other dike is similar in texture and mineral composition, but has quite sharply defined walls, next to which the texture is less coarse. At one end, however, this dike grades imperceptibly into the same pegmatite wall rock which it elsewhere intrudes sharply. These are plainly examples of contemporaneous pegmatite dikes.

PARIS.

The writer's observations extend over only those portions of the town of Paris lying between South Paris and Paris and from there northeastward to the Buckfield line. The rocks are quartz-mica schists intruded by pegmatite, quartz veins, and occasional small trap dikes. The schists reveal their original sedimentary character in the preservation here and there, as at the Crocker Hill mine near Paris Hill, of distinct bedding planes due to an alternation of highly quartzose layers with others that are more argillaceous. In a few localities small beds of crystalline limestone occur in the schists.

The collection of the Sheffield Scientific School of Yale University contains some fine diamond-shaped crystals of muscovite from the northern part of the town of Paris.

The only locality in the town where the pegmatites have proved of economic importance is Mount Mica, near Paris Hill.

HILL NORTH OF CROCKER HILL.

Certain relations observed on the next large hill north of Crocker Hill, about 2½ miles from Paris village, bear on the origin of the pegmatite and their physical characters at the time they were intruded.

Nearly the whole hilltop is bare, and fully three-quarters of the rock is a quartz-orthoclase-muscovite-black tourmaline pegmatite, which has been broken into at one place in a search for beryl of gem quality. At this opening the feldspar is sufficiently free from black tourmaline and occurs in large enough crystals to be of commercial grade for pottery purposes, but its total quantity is very small, most of the pegmatite of the hill being too quartzose and too intimately shot through with black tourmaline to be of commercial value under present conditions. The rock associated with the pegmatite is a schist or gneiss similar to that at Mount Mica, but more intensely injected by quartz and feldspar and more highly garnetiferous. It almost certainly represents a schist of sedimentary origin subsequently injected by pegmatitic material. Garnets are very abundant in this gneiss and some are 1½ inches in diameter. There are also some knots or lenticles made up entirely of quartz and garnet in irregular association. Most of these are under 1 foot in greatest dimension, but one observed was 8 feet long and 1½ feet in greatest width. A band 2 to 3 feet in width in the gneiss and traceable for about 25 feet is fully three-quarters garnets up to 1½ inches in diameter, the interspaces being occupied by quartz and some feldspar. In all probability this profusion of garnets is a contact-metamorphic effect of the pegmatite intrusion. The prevailing strike of the gneiss is about N. 45° W.

The boundaries of the larger masses of pegmatite may parallel the banding of the gneiss or break directly across it. Considerable differences exist in the trend of the gneiss, even in outcrops only 20 feet apart; this is not due to gradual curving of the folia, the changes being abrupt and due to bodily displacements of blocks of the schist during the intrusion of the pegmatite. The absence of any great amount of softening of the schist consequent on the intrusion of the pegmatite is also well illustrated by Plate X, *A*, in which is shown a pegmatite mass 2 to 3 feet across and a number of smaller masses, all intrusive in the gneiss. The gneiss folia do not in general conform to the outline of the pegmatite mass, as they would if any considerable amount of softening of the schist had occurred, and only in a zone an inch or two wide along the contact of the gneiss and pegmatite do they show distortion. Any considerable softening, therefore, seems to have been confined to a zone 1 to 2 inches wide. The bending of the gneiss folia in a manner such as is shown in the figure also indicates that the pegmatite when intruded behaved to a certain extent like a solid body, and was capable of exerting differential thrust on its inclosing walls of gneiss. In a body behaving essentially like a liquid, pressure would become equalized in all directions, and it is difficult to see how such bending could have been produced.

The pegmatite of the hill is cut by a number of quartz veins or dikes mostly under 6 inches wide and mostly subparallel in trend. Most of them parallel the rather poorly defined system of joints in the pegmatite. Some of the quartz veins possess sharp boundaries; others are rather vaguely delimited from the bordering pegmatite. Quartz veins of the latter type are particularly likely to contain some feldspar (orthoclase-microcline, some of the crystals 3 inches across) and some muscovite and black tourmaline. Black tourmaline is also found frequently in veins which otherwise are composed wholly of quartz; in some of the narrower veins it may be even more abundant than the quartz. The two often show interpenetration. At one place the relations shown in figure 3 (p. 19) were observed within a space 3 or 4 feet square. The pegmatite is in sharp contact with the gneiss, into which it sends off a tapering apophysis. The latter for a short distance from the main pegmatite mass is true pegmatite, but beyond this becomes rapidly more quartzose. Most of this branch vein consists wholly of quartz.

The inferences to be drawn from the relations described may be summarized as follows:

(1) The relations shown in Plate X, *A*, and the fact that the changes in trend of the schists are abrupt and due to displacement of schist blocks en masse indicate that the pegmatite intrusions produced no extensive softening of the schists. Such softening, when present at all, was confined to a zone an inch or two wide immediately adjacent to the pegmatite. (2) The bending of gneiss folia next the pegmatite (see Pl. X, *A*) suggests that the dike, even before its border portions had entirely solidified, behaved essentially as a rigid body capable of transmitting differential thrust and not as a liquid.

The relations shown in figure 3, the fact that feldspar, muscovite, and black tourmaline occur in many of the quartz veins, and the fact that these veins are in some places not sharply differentiated from the inclosing pegmatite, indicate that at least many of the quartz veins are to be regarded as end crystallizations from the pegmatite magma.

MOUNT MICA.

History.—Mount Mica, a small hill situated about 1½ miles east of the village of Paris at an elevation of approximately 900 feet, is one of the most famous mineral localities in the United States, and is known to mineralogists all over the world because of the size and beauty of its tourmaline crystals.

The discovery of its mineral wealth dates back to the year 1820,[a] when two students, Elijah S. Hamlin and Ezekiel Holmes, the former a resident of the town of Paris, becoming interested in the study of mineralogy, spent much time in searching for minerals in the exposed ledges and the mountains around the village. In returning from one of their expeditions in the autumn of 1820, Hamlin's eye was caught by a gleam of green from an object caught in the roots of a tree upturned by the wind. The object proved to be a fragment of a transparent green crystal lying loose upon the earth which was still attached to the roots of the tree. This was the first colored tourmaline taken from the locality which afterwards yielded them so prolifically, but its character was not recognized until somewhat

[a] Hamlin, A. C., The history of Mount Mica, Bangor, Me., 1895.

later, when the same students sent similar crystals for identification to Professor Silliman, of Yale.

The winter's snows setting in the night after the discovery prevented further exploration until the following spring, when the two students searched the bare ledge and the overlying soil and were rewarded with thirty or more crystals of tourmaline of remarkable beauty and transparency, with which were associated masses of purplish red to pink lepidolite and splendid crystal groups of white and of smoky quartz.

Subsequent examination indicated that the ledge was perforated with cavities in which the tourmalines and other minerals had been deposited and that the crystals that had been gathered by the students had been set free from their cavities by the disintegration of the surface of the ledge. Parts of the ledge were fairly honeycombed with small cavities and soft spots where the decomposing feldspar was crumbling away. In these cavities and decayed places other tourmalines were obtained by breaking away the edges of the cavities or removing the decomposed material.[a]

The finding of the first of the large pockets is described by Mr. Hamlin[b] as follows:

Two years after the discovery (1822), the two younger brothers of the discoverer, Cyrus and Hannibal Hamlin, although scarcely in their teens, resolved to make a more complete exploration of the ledge. Having borrowed some blasting tools in the village, they proceeded to the hill and managed in a rough way to drill several holes in the ledge and blast them out. These operations, though of trivial magnitude, were attended with unlooked-for results, for the explosions threw out, to the astonishment of the boys, large quantities of bright-colored lepidolite, broad sheets of mica, and masses of quartz crystals of a variety of hues. The last blast exposed a decayed place in the ledge, which yielded readily to the thrusts of a sharpened stick or the point of the iron drills. As the surface was removed, great numbers of minute tourmalines were discovered in the decomposed feldspar and lepidolite. The rock became softer and softer as the boys proceeded in their work of excavation, and soon they reached a large cavity of two or more bushels capacity. This hollow place, or rotten place, appeared to be filled with a substance resembling sand, loosely packed. Amongst this sand or disintegrated rock, crystals of tourmaline of extraordinary size and beauty were found scattered here and there in the soft matrix. Scratching away with renewed energy, the boys soon emptied the pocket of its contents, and found that they had obtained more than twenty crystals of various forms and hues. One of these was a magnificent tourmaline of a rich green color and a remarkable transparency. It was more than 2¼ inches in length by nearly 2 inches in diameter, and both of its terminations were finely formed and perfect.

Several others possessed extraordinary beauty, and some of them were quite 3 inches in length and an inch in diameter. The colors of these tourmalines were quite varied, but were chiefly red and green. * * * The exact number of the crystals obtained by the boys is not known, but when collected together with the fragments of others they filled a basket of nearly two quarts capacity. Besides the tourmalines, the quantity of lepidolite, mica, and other choice minerals thrown out by the blasts or found in the sides of the cavity was so great that the boys were obliged to seek for an ox team to transport them home.

From 1822 until 1864 the locality was visited by many mineralogists, geologists, and mineral collectors, who excavated to some extent

[a] Op. cit., p. 10.

[b] Op. cit., pp. 11-12.

GENERAL VIEW OF THE TOURMALINE QUARRY AT MOUNT MICA IN NOVEMBER, 1908. LOOKING WEST.

The upper layers of rock in the middle ground are the schist capping. In the foreground is the gigantic pocket shown in Plate XIII. The rock at the right is waste, piled in the worked-out portions of the pit.

and secured a number of valuable and beautiful tourmalines, though no systematic working was attempted. Observations were made by Professor Shepard, of Amherst College, between 1825 and 1830.[a]

In 1864 Samuel R. Carter, of Paris, commenced work in front of the pit made by former explorers and started a cut in the ledge 40 or 50 feet to the west, intending to strike the mineral belt at a depth greater than had before been reached, but after removing many tons of rock and finding no sign of the deposit he stopped work. Shortly after the close of the civil war A. C. Hamlin, the discoverer of the deposit, made a few test blasts and discovered a small pocket showing green tourmalines touched at the base with pink. In 1871 he renewed his work and after some excavation disclosed a pocket containing one of the finest crystals of white tourmaline (achroite) that has ever been found. This was 4½ inches in length and 1½ inches in diameter, white at the top, but changing to a smoky hue toward the base, and tipped at both ends with green. It is now in the mineralogical museum of Harvard College. About 1873 Mount Mica was worked for muscovite by a party of explorers and the contents of several fine pockets which they opened were scattered or destroyed. About 1880, in order to continue the work for gem minerals, Dr. Hamlin formed the Mount Mica Company and continued to operate intermittently and with varying degrees of success until about 1886, when work was suspended owing to the belief that the deposit did not extend farther to the east. In 1890 Loren B. Merrill, who had been engaged to some extent in gem mining at Mount Apatite, and L. Kimball Stone, both of Paris, purchased the rights to operate the property and have worked it successfully to the present time.

Mount Mica was visited by the writer in August, 1906, and again in October, 1907, and November, 1908. In 1908 the pit was about 150 feet long from northeast to southwest and from 50 to 100 feet wide. The maximum depth was about 20 feet. W. H. Emmons, who visited the mine in July, 1910, reports that the pit was then 300 feet long and 35 feet in maximum depth. These dimensions do not mark the total area which has been worked over, for most of the quarry waste has been piled in the abandoned workings. Plate XI gives a general view of the quarry.

Gem-bearing zone.—As at most of the Maine quarries where pegmatite deposits are worked the relations between the pegmatite and the wall rock and between pegmatite of various degrees of coarseness are very irregular. The general position of the gem-bearing zone and its relation to the bordering schists is, however, rather clear. Figure 8 represents a section through the mine from northwest to southeast,

[a] Shepard, C. U., Mineralogical journey in the northern parts of New England: Am. Jour. Sci., 1st ser., vol. 18, 1830, pp. 293-303.

the portions excavated previous to 1908 being inclosed in a dotted line. As shown in this diagram, the Mount Mica pegmatite mass dips gently 20° to 30° SE., being intruded in general parallel to the trend of quartz-mica schists, which at the quarry strike N. 50° to 60° E. and dip 20° to 30° SE. The significance of certain schist fragments inclosed in the pegmatite is discussed on page 135.

The schists are unquestionably of sedimentary origin but are locally so much injected by narrow sheetlike offshoots from the larger pegmatite masses that they resemble igneous gneisses. The contact of the pegmatite on the schist is generally very sharp and there is no indication of any absorption of the schist, though the abundance of garnets near the contact indicates some contact metamorphism.

The whole pegmatite mass is not productive (see fig. 8), the gem and pocket bearing portion constituting a zone ranging from a few inches to 6 or 7 feet in thickness lying immediately below the schist capping. The productive layer originally outcropped at the surface, a relation to which was due its discovery and the ease with which it was worked in the early days. At present the southeastern wall of

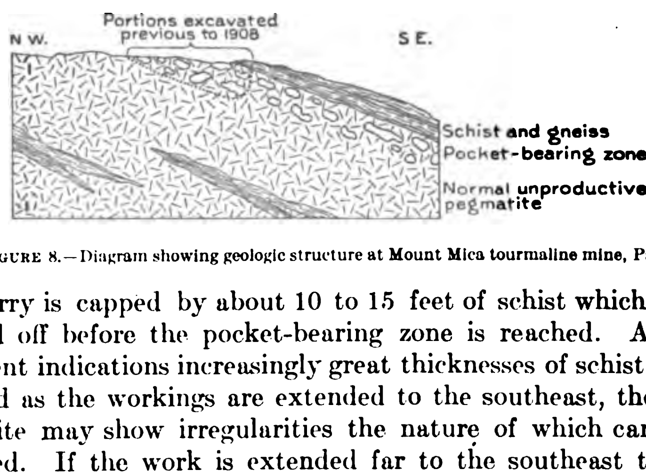

FIGURE 8.—Diagram showing geologic structure at Mount Mica tourmaline mine, Paris.

the quarry is capped by about 10 to 15 feet of schist which must be stripped off before the pocket-bearing zone is reached. According to present indications increasingly great thicknesses of schist must be removed as the workings are extended to the southeast, though the pegmatite may show irregularities the nature of which can not be predicted. If the work is extended far to the southeast tunneling may be found to be cheaper than stripping. There is very little question, however, that further lateral excavation to the southwest and northeast of the present workings, in prolongation of the original line of outcrop of the pocket-bearing zone, would disclose a continuation of the productive layer. Prospecting at least along these lines should be undertaken before the excavations are carried to any great depths in a southeast direction along the dip of the deposit.

The gem-bearing zone is not very sharply differentiated from the pegmatite below it, but is in general somewhat coarser and is separated from the underlying unproductive pegmatite by a narrow layer very rich in small garnets. This layer is similar to the garnetiferous bands observed at the Wade and Pulsifer quarry in Auburn,

REPRODUCTION OF AN OLD PHOTOGRAPH OF THE MOUNT MICA TOURMALINE MINE AT THE TIME WHEN THE POCKET-BEARING ZONE WAS CLOSE TO THE SURFACE.

The position of each pocket is marked by a stick with a white card attached. (From a negative in the possession of Mr. T. F. Lamp, of Portland.)

and it was clearly recognized by A. C. Hamlin as marking the line between the productive and unproductive rock. Out of the 80 pockets known to him previous to 1895, not one was found below this garnetiferous layer, nor have later excavations revealed any. The pocket-bearing zone is further differentiated from the rest of the pegmatite by the abundance of clevelandite, lepidolite, and some other minerals not found elsewhere.

Pockets.—An idea of the abundance of pockets may be gained from Plate XII, a reproduction of an old photograph showing the workings at a time when the pocket-bearing zone could be reached by very shallow excavation. In this picture the position of each pocket is shown by a small stick with a white card attached. The abundance of pockets differs greatly in different parts of the mineral zone, as does also their richness in tourmalines, so that certain portions of the productive zone have proved much more valuable than others. Most of the pockets are more or less spherical in outline, but some are very irregular, many consisting of several connected cavities. Few of them are angular in form. One that may be regarded as of average shape, though somewhat above the average in size, is shown in Plate IX, *B*, and is 3 feet in diameter. In size they vary from those having a capacity of only about a pint to one which was 20 feet long, 12 feet wide, and 7 feet high and contained three connecting chambers. This largest known pocket is shown in Plate XIII. One pocket 6 feet below the surface of the ledge, found in 1868, was scarcely larger than the hand and contained nothing but one transparent tourmaline crystal 3 inches long and 1 inch in diameter.[a] The total number of pockets found up to October, 1907, was estimated at 430, of which 350 have been found by Merrill & Stone, the present operators. Only a small proportion, however, yielded any gem material; out of 60 opened by Merrill & Stone in one autumn, only five or six yielded anything of value, and out of the entire 350 opened by them only about 50 were worth much.

According to Dr. Hamlin,[b] "The cavities generally were roofed with albite, whilst the sides were composed of limpid or smoky quartz mixed with lepidolite, crystals of tin (cassiterite), spodumene, amblygonite, and other rare minerals."

Few pockets were observable at the time of the writer's visit, but Hamlin's description is probably essentially correct, although albite was not observed to be any more abundant above the pockets than below them or at their sides.

The action of frost and percolating water has in most places produced much disintegration in the walls of the cavities, and their floors are generally formed of a sandy or clayey mass consisting of partly decomposed fragments of clevelandite and lepidolite associated in

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[a] Hamlin, A. C., The history of Mount Mica, p. 63 and Pl. XV.

[b] Idem, p. 49.

greater or less abundance with kaolin and the hydromica cookeite. In this mass of decomposed material the tourmalines are embedded. There can be no doubt that they were once attached to the walls of the cavities, but they have been loosened from their original position, many being fractured in the process, and now lie in every conceivable position in the material forming the floor of the cavity. Many of the groups of quartz crystals which adorned the walls have been loosened in a similar way, some of them now lying embedded in the materials of the floor with the apices of the crystals downward just as they fell from the roof of the cavity. In some of the cavities the amount of kaolinic material is very large, about a ton of the pink kaolin montmorillonite having been taken from the large one shown in Plate IX, *B*.

Minerals.—The bulk of the pegmatite found at this quarry is in general similar to that at other pegmatite workings in Maine but differs from these in the relative scarcity of graphic intergrowths of quartz and potash feldspar. The principal constituent minerals are quartz, orthoclase and microcline, muscovite, biotite, and black tourmaline, and their association seems to be wholly irregular. Even in the pocket-bearing layer these are the principal minerals, though here the clevelandite variety of albite, lepidolite, and colored tourmalines are also found.

Quartz is present in the solid pegmatite, principally in small irregular opaque masses which are white to slightly smoky in color. Rarely it is graphically intergrown with feldspar. In the pockets it occurs as groups of very perfectly developed transparent colorless crystals. Where these have become detached from the walls they may lie embedded in kaolin and cookeite in the bottom of the pockets.

The principal feldspar is buff-colored orthoclase and microcline, occurring mainly in small, irregular masses intergrown with the other common pegmatite minerals. A very few masses of pure feldspar as much as 2½ feet across were observed. The dump is now (1910) being picked over by the Maine Feldspar Company, of Auburn, to obtain spar for pottery purposes, but before this the feldspar was not utilized in any way. In the pocket-bearing zone pure white albite of the clevelandite variety is abundant, associated particularly with lepidolite, muscovite, and quartz.

Muscovite occurs in graphic intergrowth with quartz and also in books, many of which are 5 to 6 inches across. One seen on the waste pile was 12 by 14 inches in size, and another was 1 foot long and 7 to 8 inches wide. A few of the books inclose long, slender crystals of opaque green tourmaline, the largest observed being 4 inches long and one-fourth inch in diameter. The finest muscovite crystal from this locality known to the writer is in the public

LARGEST POCKET EVER FOUND AT MOUNT MICA.

This pocket measures 20 by 12 by 7 feet and contains three connecting chambers. Mr. Merrill at the right.

library at Paris and is a clear, perfect piece of roughly hexagonal outline, measuring about 8 by 2½ inches. Good specimens of plumose mica, produced by close-spaced ruling, are also to be found in the collections at Paris. Where not too intimately mixed with other minerals, the mica is saved in the quarrying process and has brought $25 per ton as taken from the quarry. At another time 12½ cents per pound was offered for the thumb-trimmed product. The largest perfect plates of cut mica obtained from this material would probably not exceed 3 by 4 inches in size. Much is defective owing to wedge structure and ruling and is valuable only as scrap mica.

Biotite is not abundant, but it occurs in a few places in its usual form of long, narrow, and very thin crystals, the largest seen being 10 inches long and one-half inch wide.

Lepidolite or lithium mica is of common occurrence in the pocket-bearing portions of the pegmatite. The largest mass found, though impure, is reported as weighing 10 tons, and it is not difficult to obtain fairly pure masses 8 or 10 inches across. The mineral occurs mostly in the granular forms, though some curved and globular crystals have been found. The color varies from lavender to peach-blossom pink. The granular varieties commonly show some admixture of quartz, muscovite, and clevelandite and not uncommonly contain interbedded crystals of opaque pink and more rarely green tourmaline; some specimens which have been sawed into small blocks and polished make handsome paperweights. Lepidolite from this locality has been described by Clarke, who also gives analyses.[a]

Black tourmaline or schorl, which is the most abundant iron-bearing mineral present at the quarry, occurs in prismatic crystals, mostly compound, many of which are a foot in length and 4 to 5 inches in diameter. A few having a length of 2½ feet were seen by the writer, and one 4 feet in length is described by Hamlin. A few large compound prisms of black tourmaline separate at their ends into a brushlike aggregate of small prisms, the interspaces being filled with quartz and an aggregate of minute muscovite scales. The black tourmalines occur in the solid pegmatite, penetrating it in all directions; except for a few small crystals, they have never been found in pockets. Some colored tourmalines occur in the solid pegmatite near the pockets, associated usually with clevelandite, muscovite, lepidolite, and quartz; a few of these are curved through considerable angles. Most of these colored crystals are opaque, though a few small, delicate, transparent ones are interleaved with muscovite. Fine specimens of these latter are found in the Carter collection in the public library at Paris; other specimens are much larger, some containing interleaved tourmalines 3 or 4 inches in length and one-fourth inch or so in thickness. In a few instances tourmalines

[a] Clarke, F. W., Lepidolite of Maine: Bull. U. S. Geol. Survey No. 42, 1887, p. 13.

cross each other with mutual penetration about at right angles, but most commonly several crystals diverge from single points, forming fan-shaped aggregates extending through 60°, 90°, or even 100°.

None of the above-described tourmalines are of gem value.

Amblygonite is the only other mineral occurring at all abundantly in the pegmatite. It is found only as a constituent of the solid pegmatite in irregular masses often 4 to 8 inches across. One mass is estimated to have weighed nearly 800 pounds. The mineral usually occurs near the pockets and is regarded as an indicator of their proximity.

Spodumene occurs in opaque gray flat crystals, usually associated with lepidolite. One crystal measured 2 feet long, 7 inches wide, and 2 inches thick. Portions of a few of the crystals are a transparent pale blue or pink. According to Mr. Merrill, an abundance of beryl or spodumene about a pocket generally signifies that the latter contains few if any tourmalines. A white spodumene crystal in the Hamlin collection at Paris is 7 inches long and 4 inches thick and is split by a wedge-shaped mass of granular lepidolite tapering from 1 inch to one-half inch in thickness.

Apatite occurs in the solid pegmatite in irregular opaque green masses, some few of which weigh a couple of pounds. A small deep-blue bipyramidal crystal one-fourth inch in length with crystal faces developed in remarkable perfection has been described and figured by Prof. E. S. Dana.[a]

Cassiterite occurs rarely, usually associated with clevelandite near the pockets. Some crystals are found embedded in the sandlike materials at the bottom of the pockets.

Columbite is rare and usually occurs in irregular bladelike crystals.

Arsenopyrite was observed in veinlike masses, mostly one-eighth to one-fourth inch in width and 2 or 3 inches in length, flanked by irregular borders of quartz, which in turn are irregularly bordered by orthoclase and microcline. The arsenopyrite therefore virtually forms the central portion of small contemporaneous quartz veins or lenses in the pegmatite.

Triphyllite occurs mostly in aggregates, many of which weigh from 10 to 20 pounds and a few as much as 50 pounds.

Zircons occur mostly associated with triphyllite, few crystals being over one-eighth inch in diameter.

Kaolin occurs in considerable amounts in the bottoms of some of the pockets as a decomposition product of feldspar. In the giant pocket shown in Plate XIV over a ton of the pink kaolin montmorillonite was aggregated at one end of the pocket.

Other minerals found at Mount Mica are autunite, brookite, childrenite, damourite, halloysite, löllingite, petalite, pyrite, sphalerite,

[a] Am. Jour. Sci., 3d ser., vol. 27, 1884, p. 480.

LARGEST CRYSTAL OF TOURMALINE EVER FOUND AT MOUNT MICA.

Length, 15⅛ inches; maximum width, 7 inches; weight, 31⅛ pounds.

yttrocerite, and zircon. Cookeite from Mount Mica has been described in detail by Penfield.[a]

Gems.—The gem tourmalines of this locality show remarkable variety in form, size, and color. Those of value occur without exception in the pockets, usually but not invariably detached from their original position on the walls and lying at the bottom in a sandlike matrix of kaolin and cookeite. Most of them range in color from olive green through emerald green to blue green; some are nearly colorless, some show beautiful pink tints, and the central portions of some are a deep ruby red when viewed along the main crystal axis; a few are the color of amber and of port wine; and some are a purplish red. Many show a zonal distribution of colors. A polished cross section of a crystal about three-fourths of an inch in diameter, preserved in the Cambridge Museum of Natural History, shows a blue-green center about one-half inch across, surrounded by a transparent pink border one-eighth inch wide, outside of which is a pale transparent olive-green border about one-sixteenth inch wide. Crystals with pink centers and olive-green borders are not uncommon. One shade commonly predominates in a pocket, but some pockets contain gems of different colors. Some single crystals shade from white at one termination to emerald green, then to light green and pink, and finally to colorless at the other termination. Green crystals tipped with pink are especially common. Generally these transitions of color are very gradual, but in some specimens the colors are not mingled in the least, and the crystals, though crystallographically continuous throughout, seem to be composed of several distinct sections.

In some pockets the tourmalines when first disclosed lie in apparent perfection of form and color in their clayey matrix, but crumble away as soon as touched. In others certain portions only of the crystals crumble away, leaving a smooth nodule of perfectly fresh tourmaline, usually beautifully transparent and in form resembling somewhat the nodules produced by the etching of quartz crystals with hydrofluoric acid. Some of the finest gems have been cut from such nodules. Some hollow crystals of tourmaline are found, commonly of small diameter, but including some as much as an inch in length; they were probably produced through disintegration of the core of the crystal. Some tourmalines have not only suffered disintegration, but have been partly or entirely removed, leaving only their impressions in the kaolin which formed the matrix.

In size the colored tourmaline crystals differ greatly, ranging from those of needle-like dimensions to the large ones described below. Many of the largest are compound.

Anything like a complete descriptive list, even of the larger and finer tourmalines found at Mount Mica, is impracticable in this report, but a few of the most remarkable will be briefly described.

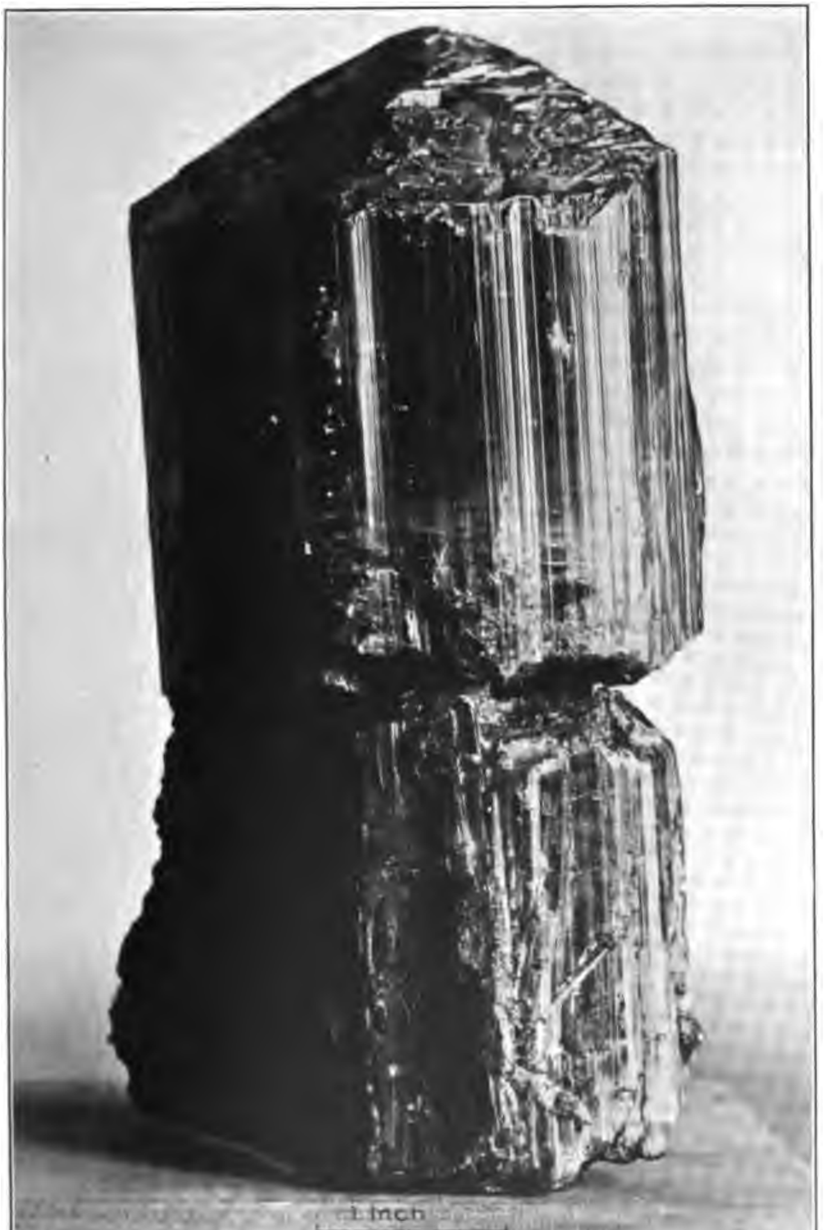
[a] Penfield, S. F., On cookeite from Paris and Hebron, Me.: Am. Jour. Sci., 3d ser., vol. 45, pp. 393–396.

The largest tourmaline ever found at Mount Mica came from the pocket shown in Plate IX, *B*, and is itself figured in Plate XIV. It is now in the Paris library, to which it has been loaned by Edward Hamlin, of Boston. It is 15½ inches long, 7 inches in maximum breadth, weighs 31½ pounds, and is valued at not less than $400. As shown in the plate, the base is fractured so that the crystal is now in three segments. The crystal is transparent to translucent grass green at the tip, where, too, the prism faces are best developed. The middle and lower flanks of the terminal segment are made up of a mass of small colorless to pale-pink or brownish prisms between one-eighth and one-fourth inch in diameter, many of them set at all sorts of angles to the main axis of the compound crystal. A small crystal of white quartz about 2 inches long is attached to the side of this segment. The basal segments, which are about 4 inches across, show an alternation of small translucent to opaque pink and green prisms, the colors grading into one another parallel to the prism axes and also across them.

The same pocket contained another compound tourmaline crystal, somewhat similar to that just described in its general form and very similar in coloring, but smaller. Its length is about 10 inches, its maximum width 3½ inches, and its weight 6½ pounds. It is now in the possession of Mr. Merrill.

Besides these two compound crystals the pocket yielded two simple crystals, one of which is shown in Plate XV in natural size. The upper segment of this is in Mr. Merrill's possession, the lower having been cut into gems. The companion crystal, which was slightly smaller, is the property of the Hamlin estate. Both crystals are green in the upper part and pink and red at the base. They are transparent to translucent, and the segment which is in Mr. Merrill's possession may contain some gem material in its upper portion. The same pocket also yielded many small crystals of green and red, which furnished about 75 carats of cut gems, mostly red and pink, but some green. Three nodules of colorless tourmaline were also found, one of which would cut an 8-carat stone. Some of these were remarkably limpid and brilliant when cut. In all, there were about 75 pounds of tourmaline crystals in this pocket. The two largest tourmaline groups and most of the others lay loose in the disintegrated clevelandite and cookeite in the bottom of the pocket. No kaolin was present. Lepidolite occurred around the walls and across the bottom. Many quartz crystals lay loose in the bottom of the pocket, the upper ones having the apices of the crystals downward, showing that they had fallen from the roof.

A large tourmaline, consisting of a bundle of prisms diverging slightly toward the apex of the crystal, is now in the Cambridge Museum of Natural History. It is 7 inches long, 3½ inches wide near



LARGE SINGLE CRYSTAL OF TOURMALINE FROM MOUNT MICA. NATURAL SIZE.

From the same pocket as the giant tourmaline shown in Plate XIV.

the apex, and 2½ inches wide at the base. Most of the crystal is a deep grass green, but at the base the outer green layers have shelled off, revealing a cone of deep pink, which, however, does not appear to penetrate far. The base, a nearly straight surface inclined about 70° to the main prism axis, appears to be a fracture surface and is conchoidal. It is partly coated with cookeite, as are the lower flanks of the prism, showing that the crystal had become detached from its original position on the wall of the pocket before the cookeite was deposited. The summit terminations are not crystal faces, but are fracture planes standing nearly at right angles to the main axis. The sides are closely and beautifully striated. The crystal is transparent to translucent and does not appear to contain any gem material. This tourmaline was the largest found in the giant pocket shown in Plate XIII. It lay loose in the bottom in a mass of kaolin and of cookeite sand. A few other smaller tourmalines were found, but none were of gem quality, and in proportion to its great size the pocket was remarkably unproductive. The pocket contained large amounts of massive and crystal quartz plugged full of small opaque tourmaline crystals. In one end there was about a ton of the pink kaolin montmorillonite.

The largest transparent crystal of green tourmaline found at Mount Mica was discovered by Samuel R. Carter in 1886 and is now in the Cambridge Museum of Natural History. It is 10 inches in length, 2¼ inches in diameter, and weighs 41 ounces. Both terminations have been preserved, but they are not at all perfect.[a] Although broken into four pieces, the parts have been easily joined by cement. Its middle portion would probably yield some fine gems. This crystal came from an unusually large pocket 4 feet in diameter, along whose sides and at whose bottom, embedded in a sand of decomposed cookeite, lepidolite, etc., were found fragments of certainly 50 well-defined tourmaline crystals.

The most remarkable crystal of white tourmaline or achroite found at this locality is also in the Cambridge Museum of Natural History. It was obtained in 1869 from a large pocket which yielded several other crystals of smaller size. This crystal is transparent, but when viewed in light transmitted at right angles to its axis appears smoky toward the base; when viewed along the axis its hue is crimson. Both ends are tipped with green, but its terminal faces are not preserved. Its length is about 4 inches and its width 1½ inches.

The finest crystal of blue tourmaline or indicolite found at Mount Mica is in the Hamlin cabinet. It is transparent throughout its entire shaft, although broken into five parts. Both terminations are preserved. The color, when viewed at right angles to the prism

[a] Hamlin, A. C., The history of Mount Mica, Pl. XXX and pp. 39-40.

length, is a beautiful sapphire blue, changing at the top into a delicate green. It is about 4 inches long and one-half inch in diameter. It is illustrated in color in "The history of Mount Mica," Plate XXVI.

A remarkable curved crystal of gray to green tourmaline, transparent to translucent in places, was found in 1891, and is now in the Carter collection in the public library at Paris. It is about 5 inches long and three-fourths to 1 inch in diameter, and is curved through an angle of about 20°.

The largest flawless gem ever cut from tourmaline from Mount Mica weighs 69¼ carats and is now in the Tiffany collection. It was part of a crystal found in November, 1893, and was sold by Merrill & Stone for $1,000. The crystal from which it came is described and figured in "The history of Mount Mica," page 71 and Plate XLIII. It yielded a number of other fine gems, one of which, a pink one, weighed 18 carats.

What is probably the largest flawless piece of transparent tourmaline known is in the possession of L. B. Merrill, its finder, the present operator of the Mount Mica mine. In its uncut condition it weighs 411 carats. It formed the tip of a crystal 8 inches long and 1 inch in diameter, much of which was greatly disintegrated.

Beryl occurs principally in the solid pegmatite, though occasionally found in the pockets. The varieties found in the solid pegmatite are mainly pale blue-green and opaque or translucent. Certain small portions of the crystals may be transparent, and from these some small aquamarines of good quality have been cut. One beryl 6 inches across, observed by the writer, inclosed both muscovite and black tourmaline. The beryl found in the pockets is mostly colorless to pale pink cæsium beryl; it cuts into gems which in artificial light have almost the beauty of diamonds. It is apt to occur in short, button-shaped prisms, many with both terminations complete. Two fine specimens of cæsium beryl are in the Hamlin collection at the Paris public library. One is about 6 inches in diameter and 1 inch high and has three sides of the hexagonal prism perfect. The other is about 6 inches high, shows a good basal plane, four prism faces quite perfect for most of their length, and two pyramid faces. These crystals are only in small part transparent and are much flawed and iron stained along fractures.

Production and method of mining.—It is impossible accurately to estimate the amount and value of material for gems and museum specimens which Mount Mica has yielded, but Hamlin in his history of Mount Mica estimated that up to 1895 the locality had yielded more than 100 tourmaline crystals which would be considered unusually fine specimens of the mineral, besides many thousand smaller crystals. The total value of the gems and cabinet specimens which have been taken from the locality up to the present day probably exceeds $50,000.

The mine is worked by Merrill & Stone, the drilling being done by hand and the blasting with black powder, so as to run as little risk as possible of shattering valuable gem material. A derrick operated by a horse windlass is used in transferring the waste rock to the dump. At present it is necessary to remove a considerable thickness of schist overlying the pocket-bearing layer. It is probable that the thickness of the cover rock increases southward, and that in the near future tunneling will be found the most economical method of working.

PERU.

The pegmatites of Peru were studied at only one locality, an old mica prospect on the farm of J. P. York near the central part of the town. The mine is located near the summit of the southwest slope of a steep hill and was worked only in the summer of 1902.

The whole pegmatite mass is hardly over 150 feet wide on the level of the principal openings and appears to have the form of an irregular lens elongate in a general east-west direction. The bordering rock is a granite gneiss locally very rich in biotite. The openings are below the crest of the hill, and as the pegmatite mass is traced eastward toward the summit it is found to be associated with larger and larger amounts of granite gneiss. The lowermost exposures on the hill slope also show much granite gneiss associated with the pegmatite; the latter therefore appears to pinch out rather rapidly both above and below, and consequently to be of rather small extent. The trend of the granite gneiss where it borders the pegmatite on the north is about N. 70° E.; its folia dip steeply to the northwest.

The pegmatite varies greatly in coarseness from point to point. Its dominant components are orthoclase-microcline, quartz, muscovite, and biotite. A few feldspar crystals are 3 feet across, but for the most part this mineral is so intimately mixed with biotite as to be commercially valueless. Locally the biotite forms blades 4 to 5 feet long and 2 to 3 inches wide. Some crystals show muscovite surrounding biotite in parallel growth. No muscovite books more than 3 to 4 inches across were seen either in the solid pegmatite or in the dump piles of the mine, and specimens preserved at a neighboring farmhouse and said to be as good as any of the mica obtained would none of them cut pieces of clear mica measuring more than 2 by 3 inches. There is no distinct vein particularly rich in muscovite and the property can not be regarded as a commercial proposition for mica mining.

RUMFORD.

The town of Rumford is occupied by quartz-mica schists, intruded and in some places intimately injected by granite and pegmatite. The relations at a number of localities throw light on the genesis of the rock concerned.

Vicinity of Rumford Falls.—The exposures examined were on the east shore of Androscoggin River at the falls, a mile or so above Rumford Falls village. The schists are dark gray to purplish on the fresh surfaces and purplish to rusty brown on the weathered surfaces. They are garnetiferous quartz-mica schists and strike N. 30° to 40° W., with dips of 20° to 30° NE. The schists are intruded by sills and dikes of fine-grained gray granite, by pegmatite, and by small quartz veins.

An instructive contact between the schist and pegmatite is shown in Plate X, *B*, and has already been described on pages 34.

Another intrusive mass in the schists is of irregular sill-like form, and consists partly of biotite granite and partly of pegmatite. It is interesting because of gradual and complete gradation between granite and pegmatite. The biotite granite is gray in color with an average size of grain of not over 1 millimeter. The pegmatite in addition to quartz and feldspar shows muscovite, but very little biotite.

A number of small dikes of fine-grained granite intrude the schists at this locality, both parallel to and transverse to the trend of the latter. All of these are characterized by sharp parallel walls and are in great contrast to the pegmatite dikes which traverse the same schists but are characterized by wavy and irregular forms, the two sides of the dike or sill in few places being parallel. The intrusion of the schist by the fine-grained granite in the railroad cut opposite the falls is so intimate that a dike network results.

Microscopic comparisons were made between the medium-grained granite of this locality and the pegmatite of an irregular dike cutting the granite. The dike is exposed for 20 feet and is 1 foot wide at its base, but broadens upward within 2 feet to a width of 4 feet, thence narrowing again within a few feet to a width of 1 foot. There is complete crystallographic continuity between the two rocks at their contact, but the transition from one to the other is usually complete in a space of one-fourth to one-half inch. The minerals characteristic of the two rocks are identical.

The granite shows considerable and irregular variations in color, due to differences in the abundance of biotite. Few of its mineral grains exceed one-eighth inch, and their average size is about one-sixteenth. Its dominant minerals are quartz, orthoclase and microcline, oligoclase (extinction angles up to 13°; refractive index about equal to balsam), and biotite. Garnet and muscovite are subordinate accessories. Oligoclase appears to be only slightly less abundant than the potash feldspars. Small quartzes of rounded cross section and a few with hexagonal outlines (some with corners rounded) are inclosed by orthoclase, microcline, or other quartz. A few small biotite laths are wholly inclosed by oligoclase, and a few rounded crystals of oligoclase are inclosed by orthoclase. These relations point to the existence in the magma of small crystals of quartz, biotite, and oligoclase not long before the bulk of the rock crystallized. A few small areas show an intergrowth, more or less graphic in pattern, of quartz with oligoclase or microcline.

The minerals of the pegmatite are identical with those of the granite, but form much larger crystals and exhibit markedly greater diversity in the size of the mineral grains. Microcline is the dominant feldspar, and much of it is perthitically intergrown with plagioclase, which appears to be albite-oligoclase in composition. The same plagioclase also forms separate crystal grains, usually much smaller than those of microcline. Biotite is abundant and has altered somewhat to chlorite. In a few places quartz is micrographically intergrown with the plagioclase. Many small quartzes of rounded outline or showing hexagonal forms with rounded corners are inclosed by the microcline. Muscovite is rare.

The mineralogical similarity of these two rocks even as regards the composition of the plagioclase, and the presence in both of small quartzes of an earlier crystallization inclosed by later feldspar, taken in connection with their close field association, suggest their derivation from the same magmatic source.

Black Mountain mica mine.—A mine which has been operated for scrap mica by Oliver Gildersleeve, of Gildersleeve, Conn., is located on Black Mountain in the northern part of the town of Rumford. The two quarry pits are hillside excavations about two-thirds of the way up the mountain on its western slope and are about three-fourths of a mile from the road between North Rumford and Roxbury Notch. The upper pit is about 200 feet long, 50 feet wide, and 25 feet in greatest depth. Another just below it on the slope is about 100 feet wide, 100 feet long, and 35 feet in maximum depth.

The rock at these pits is an exceedingly coarse pegmatite which is intrusive in an irregular manner in metamorphosed sediments trending N. 30° to 40° W. and dipping 70° to 80° NE. The latter are slightly contorted but reveal their sedimentary origin through an alternation of quartzitic and more shaly beds.

The pegmatite here shows some characters which differentiate it from any of the other deposits studied, though in general its characters approach more closely to the pegmatite of the gem-tourmaline localities than to that of the other mica prospects in the State. Potash feldspar is almost entirely absent, the dominant feldspar being albite of the bladed clevelandite variety. Muscovite is the mineral next in abundance, constituting about 30 to 40 per cent of the whole deposit. Locally, however, it forms three-fourths of the pegmatite mass. The largest crystal of mica seen by the writer was 1½ feet wide and 3 feet long, but blade-shaped or spearhead-shaped crystals, 1 to 2 feet long, are very common. Some masses weighing half a ton are almost purely mica. All of the mica shows one or more of the defects known as twinning, wedge structure, and ruling. None of it will yield any plate mica. Several of the mica books observed were 1 foot thick (at right angles to the cleavage). Near the walls of the pegmatite mass the mica books tend to orient themselves with their long axes perpendicular to the contact, though only within 6 inches or so of the wall is there any noticeable decrease in the coarseness of the pegmatite. The quartz of this pegmatite is mostly opaque but is pure white. Spodumene is unusually abundant in long flat crystals, some of them 2½ feet long and 3 to 4 inches thick. The color is light gray to white. Some of the spodumene is intimately intergrown with quartz.

A remarkable feature of this deposit is the presence in the pegmatite of irregular masses of medium-grained granite, which in some parts consists of muscovite, quartz, and plagioclase, and along certain bands or irregular bunches is one-third to one-half bright pink tourmaline, producing a stone of considerable beauty. Under the microscope the principal minerals are seen to be quartz, muscovite, pink tourmaline, and basic oligoclase (extinction angles up to 17°; refractive index near balsam). In the thin section only very faint pleochroism is seen in the tourmaline. Tourmaline constitutes the largest crystals in the rock and shows a tendency toward the development of radiate bundles, one-eighth to one-fourth inch across, made up of small prisms. The average size of grain, exclusive of the tourmaline crystals, is from 0.3 to 0.6 millimeter. This granite is plainly a crystallization from the pegmatite magma and, like the pegmatite, numbers quartz, muscovite, and pink tourmaline among its chief constituents. Many large spodumene crystals are embedded in this tourmaline granite. Its quantity and uniformity are not sufficient to give it any commercial importance.

In the pegmatite, greenish-black tourmaline occurs in crystals averaging one-half inch to 1½ inches in diameter and 4 to 8 inches in length. They are commonly associated with quartz or clevelandite and only rarely are in contact with muscovite, being rare in the more micaceous parts of the pegmatite. Pink to gray opaque tourmaline also occurs, generally surrounded by quartz. One aggregate exposed in a loose quartz fragment is 7 inches long. It is a brush-shaped aggregate of tourmaline crystals and enlarges from a diameter of about 2½ inches at the base to about 4 inches at the top, the cross section being nearly circular.

Most of the schist exposed near this mine is somewhat weathered. Noticeable contact metamorphism, though confined to the immediate vicinity of the pegmatite, has been more severe than along most of the pegmatite contacts studied. It has resulted in the abundant development of prisms of cinnamon-brown tourmaline from one-fourth to one-half inch long and one-sixteenth to one-eighth inch in diameter in certain of the more muscovitic layers. More biotitic portions present a mottled appearance, due to the occurrence of the biotite in irregular aggregates one-eighth to one-fourth inch in diameter. Under the microscope this mottled rock is seen to consist of brown biotite, light-green hornblende, quartz, labradorite, titanite, magnetite, and apatite, the latter in small hexagonal prisms filled with a cloud of very minute inclusions. The tendency to aggregation of the biotite, hornblende, titanite, and magnetite gives the mottled appearance, the white intervening areas being largely quartz and labradorite. The mineral grains of this rock are interlocking and the texture granular and indistinguishable from that of an igneous rock. Field relations show, however, that the rock is a phase of the sedimentary schist wall rock which has undergone complete recrystallization.

It is notable that neither of the metamorphosed phases of the wall rock described above contains any minerals except the common ones, quartz and muscovite, that are characteristic of the neighboring pegmatite. The tourmaline of the schist is brown and wholly dissimilar from any found in this or any other pegmatite of the State. Additions, if any, received by the wall rock from the pegmatite during the complete recrystallization of the former were ionic in their character, the minerals characteristic of the pegmatite, with the possible exception of quartz, not being added as such to the intruded rock.

The quarry was opened in about 1901 by Oliver Gildersleeve and has been worked for four seasons. About 250 tons of mica is reported to have been mined in 1905. The quarry was idle throughout 1906, in which year the writer visited it, and so far as is known has not reopened since. Steam drills were employed and sheds built for hand picking the mica, which was packed in 100-pound bags and hauled by team 7 miles to Frye, on the Rangeley division of the Maine Central Railroad. From Frye it was shipped to a grinding mill at Gildersleeve, Conn. About 1,000 tons in all are reported to have been shipped. The quantity of scrap mica still available at this quarry is large, but there is no plate mica, nor is it probable that further excavation will disclose any. It is doubtful if at present the property can be profitably exploited for scrap mica in view of the fact that the refuse cuttings from plate mica properties appear able to meet entirely the present demand for scrap mica.

STANDISH.

The rocks of Standish were studied only in the western part of the town, in the Spence Hills, which lie about 5 miles north-northeast of Paris village. The rocks are schists of the same metamorphic-sedimentary type observed in the town of Paris, and are rather flat lying. As in Paris, they are intruded by granite and pegmatite, but these rocks are much less abundant than at most places in Paris, and large masses of the schist are wholly free from granitic material of any kind.

The collection of the Sheffield Scientific School of Yale University contains several fine crystals of columbite from the pegmatites of this town.

STONEHAM.

GEOLOGY.

The rocks of the town of Stoneham are almost exclusively gneisses intruded by pegmatite and granite, the igneous rocks being on the whole more abundant than in most of the towns to the east.

Excellent exposures on the south shore of Keewaydin Lake (Lower Stone Pond), near the village of East Stoneham, show rather fine-grained pegmatite intruding a purplish-gray gneiss, indistinguishable in the field from certain gneisses exposed at the Auburn reservoir site on Goff Hill. This rock is a quartz-feldspar-muscovite-biotite schist whose origin can not be definitely stated. It closely resembles many phases of the sedimentary schists which have been intensely injected by pegmatite and may be of similar origin. Both schist and pegmatite are intruded at "Striped ledge," on this lake, by a remarkable dike network of fine-grained diabase. (See Pl. XVI, *A*.)

Granite found a few miles west of Keewaydin Lake, in the bed of a creek flowing into Upper Kezar Lake, is a millimeter-grained, light-gray rock, in which a faint gneissic habit is recognizable, due to the occurrence of biotite in slightly greater abundance along certain vaguely defined bands than along others. The microscope shows its minerals to be quartz, albite, biotite (partly altered to chlorite), and a little muscovite. The rock differs from most of the granites of Maine in being a soda granite, potash feldspar being apparently wholly absent. The microscopic texture is typically granitic.

GEM LOCALITIES.

Pegmatites have not been systematically worked at any place in this town but have yielded to prospectors and mineral collectors a large number of beryls, some of which are among the finest of their kind, and also fine specimens of topaz, amethyst, beryllonite, and other minerals. Some of the finest of these specimens have been obtained from localities which can not now be identified.

A. NETWORK OF DIABASE DIKES CUTTING PEGMATITE AND ASSOCIATED GNEISS AT KEEWAYDIN LAKE, IN STONEHAM.

B. QUARTZ DIKE CUTTING PEGMATITE AT HOWE QUARRY, SOUTH GLASTONBURY, CONN.

Showing light-colored feldspar crystals with well-developed crystal faces projecting into the quartz of the dike. The quartz appears dark in the photograph.

Sugar Hill.—Two fine aquamarines, found near Sugar Hill, in the western part of Stoneham, are described as follows by Kunz: [a]

> The writer obtained at Stoneham, Oxford County, Me., two beryls, exceptional for the United States. These were found in 1881, several miles apart and several miles from the topaz region, by farmers who were traversing pastures in the township. The first was found in two pieces, as if it had been roughly used, and broken, and discarded as worthless, or else broken in taking from the rock and then rejected, its value not being known. This crystal measured $4\frac{3}{4}$ inches (120 millimeters) long and $2\frac{1}{10}$ inches (54 millimeters) wide, and was originally about 5 inches (130 millimeters) long and 3 inches (75 millimeters) wide. The color was rich sea green viewed in the direction of the longer axis of the prism, and sea blue of a very deep tint through the side of the crystal. In color and material this is the finest specimen that has been found at any North American locality, and the crystals, unbroken, would equal the finest foreign crystals known. It furnished the finest aquamarine ever found in the United States, measuring $1\frac{3}{8}$ inches (35 millimeters) by $1\frac{3}{8}$ inches (35 millimeters) by three-fourths inch (20 millimeters). It was cut as a brilliant and weighs $133\frac{3}{4}$ carats. The color is bluish green, and, with the exception of a few hair-like internal striations, is perfect. In addition to this remarkable gem, the same crystal furnished over 300 carats of fine stones.
>
> The other crystal is doubly terminated, being $1\frac{5}{8}$ inches (41 millimeters) long and $\frac{5}{8}$ inch (15 millimeters) in diameter. Half of it is transparent, with a faint green color; the remainder is of a milky green and only translucent.

The large 133-carat gem cut from the first of these two crystals is now in the possession of the Field Museum of Natural History at Chicago.

Fine crystals of golden beryl have been obtained at Edgecomb Mountain in Stoneham.

On the south flank of Sugar Hill a ledge of coarse pegmatite has yielded a number of fine transparent beryls. The pegmatite mass here appears to be rather flat lying and, as exposed in a near-by vertical face, is at least 15 feet in thickness; it can be followed for 100 feet or so along the hillside. The buff-colored potash feldspar of this ledge forms large enough crystals and is sufficiently free from iron-bearing minerals to be of commercial grade for pottery purposes, but its distance from the railroad would render its exploitation unprofitable at the present time.

Crystals of beryllonite, a phosphate of beryllium and sodium, have been found in western Stoneham on the farm of Eldin McAllister, on the south side of Sugar Hill, a few rods below the beryl locality just described. When visited by the writer, in September, 1906, the only opening consisted of a small pit dug in the talus and glacial drift near the foot of the hill. The soil in which the beryllonite crystals were found contains also fragments of quartz, feldspar, and mica, and a few of apatite, beryl, cassiterite, columbite, and triplite. Some of the beryllonite crystals themselves are attached to apatite and some retain what appear to be the impressions of muscovite crystals. There can be little doubt therefore that the beryllonite occurred

[a] Kunz, G. F., Gems and precious stones, pp. 92-93.

as a constituent of a pegmatite mass, and it probably occurred in pockets. The minerals were probably dislodged, by the action of glacial ice, from a decomposed pegmatite ledge somewhere on the flanks of Sugar Hill and were subsequently deposited in their present position at the base of the hill. Prospecting on the hill northwest of the beryllonite locality may eventually disclose the source.

The locality was first worked by E. D. Andrews, of Albany, who, in searching for smoky quartz, found an unknown mineral, which was later identified by E. S. Dana in 1888 as a new species and called beryllonite. Its mineral characters have been fully described by Dana and Wells.[a]

Harndon Hill.—A well-known topaz locality is located on the summit of Harndon Hill, in the southwestern corner of the town of Stoneham, within one-fourth mile of the Stow line. It was opened in the early eighties by Nathan H. Perry, of South Paris, and worked intermittently for a number of years, but at the time of the writer's visit in September, 1906, had been practically idle for over ten years. The workings consist of several openings close together, a few feet across and 2 or 3 feet in depth, in the coarse pegmatite which caps the hill at this point.

The locality has been visited by George F. Kunz, of New York, and its minerals described by him.[b] He describes the character and mode of occurrence of the topaz as follows:

> This locality is the first in New England that has furnished good, clear, and distinct crystals of topaz, and thus far it has produced the best crystals found in the United States. Of these crystals, nearly all the finest were found in one pocket in clevelandite (lamellar albite) at its junction with a vein of margarodite (hydromica) and one was entirely surrounded by clevelandite. The finest crystals vary in size from 10 millimeters to the largest, which measures transversely 60 by 65 millimeters and vertically 56 millimeters. They are transparent in parts, and contain cavities of fluids, the nature of which has not yet been determined. A few small perfect gems have been cut from the fragments of a large crystal that was broken.
>
> The finest crystals are colorless or faintly tinted with green or blue. Some opaque crystals are as much as 300 millimeters across the largest part and weigh from 10 to 20 kilograms each. They are not perfect in form, the faces are rough, and generally they were broken before they were taken from the rock. The color in these rough crystals is more decided than in the finer ones and is a light shade of either green, yellow, or blue. The specific gravity of the transparent material is 3.54, and the hardness the same as that of the yellow topaz from Ouro Preto (formerly Villa Rica), Brazil.

The properties of this topaz have been further discussed by Penfield and Minor;[c] its chemical composition has been studied and its alteration to damourite has been described by Clarke and Diller.[d] No topaz was visible at the time of the writer's visit.

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[a] Dana, E. S., and Wells, H. L., Am. Jour. Sci., 3d ser., vol. 37, 1889, pp. 23-32.

[b] Kunz, G. F., Topaz and associated minerals at Stoneham, Me.: Am. Jour. Sci., 3d ser., vol. 27, 1884, pp. 212-216.

[c] Penfield, S. L., and Minor, J. C., jr., On the chemical composition and related physical properties of topaz: Am. Jour. Sci., 3d ser., vol. 47, 1894, p. 390.

[d] Clarke, F. W., and Diller, J. S., Topaz from Stoneham, Me.: Am. Jour. Sci., 3d ser., vol. 29, 1885, pp. 378-384.

Other constituents of the pegmatite at this locality are the following, the descriptions being partly those of Kunz:

1. Apatite occurs in the cavities as small doubly-terminated crystals and in the solid pegmatite as opaque vitreous-green masses weighing up to 2 pounds.

2. Beryl occurs in large colorless to pale-green crystals embedded in the solid pegmatite. Most of them are opaque to translucent with small colorless transparent portions. Kunz reports that one band unusually rich in beryl was traced for nearly 40 feet. Some of the crystals in this band were about a yard long and over a foot across.

3. Clevelandite in white plates is very abundant, as in most of the gem-bearing pegmatites. It occurs in particular abundance and perfection of crystal form on the walls of the pockets.

4. Columbite is usually associated with clevelandite, lying either on crystals of the latter in cavities or else between the plates of it. Its crystals vary in length from 1 to 10 millimeters and are not very perfect. One pocket afforded over 40 pounds of pure material, and one mass which seemed to have belonged to a single crystal group weighed over 17 pounds.

5. Fluorite fills small cavities in the clevelandite. The masses are rarely over 10 millimeters across and the color is very deep purple. A number of very minute octahedra resembling blue topaz have been found.

6. The pink kaolin montmorillonite occurs, according to Kunz, in masses that range in color from a very delicate pink to tints closely approximating red, filling the cavities and interstices in the clevelandite. It also occurs in botryoidal masses resembling rhodochrosite, on crystals of clevelandite.

7. Triplite is scattered irregularly through the solid pegmatite in masses usually under 2 pounds in weight, though one mass broken out in the blasting furnished over 100 pounds of rather pure material.

8. Herderite, in short prisms from 1 millimeter to 1 centimeter long, occurs in the topaz-bearing pockets and has been described by Hidden and Mackintosh [a] and further discussed by Dana [b] and Penfield.[c]

9. Bertrandite occurs in the pockets with herderite and topaz. It has been described by Penfield.[d]

10. A single occurrence of hamlinite has been noted at this locality. The mineral formed minute rhombohedral crystals attached to herderite, margarodite, muscovite, and feldspar, and associated with ber-

[a] Hidden, W. E., On the probable occurrence of herderite in Maine: Am. Jour. Sci., 3d ser., vol. 27, 1884, p. 73. Hidden, W. E., and Mackintosh, J. B., On herdérite, a glucinum calcium phosphate and fluoride from Oxford County, Me.: Idem, pp. 135–138.

[b] Dana, E. S., On the crystalline form of the supposed herderite from Stoneham, Me.: Idem, pp. 229–232.

[c] Penfield, S. L., On the crystallization of herderite: Am. Jour. Sci., 3d ser., vol. 47, 1894, pp. 333–336.

[d] Penfield, S. L., Crystallized bertrandite from Stoneham, Me., and Mount Antero, Colorado: Am. Jour. Sci., 3d ser., vol. 37, 1889, pp. 213–215; Note concerning bertrandite crystals from Oxford County, Me.: Idem, 4th ser., vol. 4, 1897, p. 316.

trandite. It was named in honor of A. C. Hamlin, of Bangor, who for many years developed the famous tourmaline mine at Mount Mica. The mineral has been described by Hidden and Penfield.[a]

Other minerals from this locality are autunite, biotite, gehlenite, garnet, muscovite, quartz, triphylite, and zircon.

STOW.

The rocks of the town of Stow, so far as seen by the writer, are all granitic; they include pegmatite, normal granite, and granite gneiss. Amethystine quartz has been obtained on Deer Hill near the New Hampshire line. When visited by the writer in September, 1906, the only openings observed were a number of shallow pits dug in the soil on the southeastern slope of the hill. The amethyst crystals occur loose in this soil or attached to loose fragments of feldspar. The small pieces found by the writer were all of a very pale lavender tint and in most of them the color was very unevenly distributed. The amethyst was probably derived from pockets in the pegmatite, but so far as known the ledge has not been opened. The whole summit of the hill is composed of pegmatite of the type usual in western Maine. Certain portions are coarse enough and sufficiently free from iron-bearing minerals to be of commercial grade for pottery purposes, but their quantity is small.

The characters of the rocks are well shown in the bed of Great River near the road bridge just southwest of Deer Hill, where the principal rock is a rather fine-grained biotite-muscovite granite, in part massive, but mostly of gneissic texture. This is crossed by an irregular band of muscovite-biotite pegmatite, which ranges from 6 inches to 2 feet in width; it is without sharp walls and grades imperceptibly into the granite gneiss. The mineralogic similarity and the gradation from one rock into the other indicate a common magmatic source. The pegmatite appears to have been intruded before the complete solidification of the granite.

From Deer Hill southward to Stow village the rocks are pegmatite and fine-grained granite. From Stow village to Lovell village the bed rock near the roads is obscured by extensive glacial outwash deposits of sand.

WATERFORD.

The rocks of Waterford, so far as seen by the writer, are largely granites and associated pegmatite, though some schist of probable sedimentary origin is found in the eastern part of the town. The pegmatite at two localities has in the past been worked for mica.

[a] Hidden, W. E., and Penfield, S. L., On hamlinite, a new rhombohedral mineral from the herderite locality at Stoneham, Me.: Am. Jour. Sci., 3d ser., vol. 39, 1890, pp. 511–513. Penfield, S. L., On the chemical composition of hamlinite and its occurrence with bertrandite at Oxford County, Me.: Am. Jour. Sci., 4th ser., vol. 4, 1897, pp. 313–316.

South Waterford mica prospect.—An old mica mine located in the southwestern part of the town near the Sweden line was visited by the writer in September, 1906. It consists of a single pit about 40 feet long, 15 feet wide, and 15 feet in depth, located on an eastern hillside. The predominant rock at this locality is a gray muscovite-biotite granite varying somewhat in texture but mostly fine grained. It differs in shade from point to point, owing mainly to variations in the amount of biotite it contains.

Under the microscope the texture is seen to be typically granitic and nearly equigranular. The rock is very fresh and consists in order of abundance of quartz, microcline, biotite, plagioclase feldspar, and muscovite. The plagioclase appears to have the composition of oligoclase (refractive index > microcline and > = < Canada balsam; extinction angles low). Much of the quartz shows rounded outlines and is inclosed by microcline. This quartz appears to represent the earliest crystallization, even the biotite plates conforming to its rounded outlines. Microcline and other quartz are plainly later crystallizations.

Locally aggregations of biotite in the granite form flat lenticles, many of irregular form and variously oriented. Biotitic aggregations are also present in the finer portions of the pegmatite.

The pegmatite penetrates the granite in an exceedingly irregular manner, locally with the most gradual transition. The pegmatite shows great variation in coarseness, the coarsest portions containing crystals of orthoclase 1½ to 2 feet across. Its mineral constituents appear to be identical with those of the granite, though present perhaps in somewhat different proportions. The dominant feldspar is microcline (with some orthoclase); oligoclase is present in subordinate amounts (refractive index > microcline and about = balsam; extinction angles up to 12° and 13°).

In texture and mineral composition the granite of this quarry is very similar to that at Rumford Falls (pp. 94–95). Both granite masses are of relatively small extent and exhibit within short distances differences in composition more marked than is characteristic of the normal granites of the large granite areas of the State. In the granite of Waterford the tendency toward segregation is further shown by the presence of the biotite nodules already mentioned. In both localities granite is so similar in mineral composition to the associated pegmatite and the gradation from one rock to the other is in many places so gradual and irregular that it seems necessary to conclude that granite and pegmatite crystallized fron the same magmatic source at nearly the same time. Some of the pegmatite shows megascopic evidence, in the presence of thin irregular skins of muscovite and other secondary foliated minerals along certain planes through the rock, of very slight internal movements subsequent to its solidification. Microscopically the effects of these movements are recognizable in local granulation within certain quartz and feldspar individuals and marked strain in others.

The coarsest portions of the pegmatite have been worked for mica. A few of the muscovite books are as much as 1 foot across, but the majority are under 4 inches. The larger plates are only in part clear, being injured by ruling and twinning. The writer saw no plates that would cut clear pieces larger than 2 by 3 inches, and even such as would were rare. Most of the material could be utilized only for scrap mica. The property hardly appears to merit further development.

Beech Hill mica mine.—Another mica mine, located a few miles north of the first, on the farm of George L. Kimball, on Beech Hill, represents the most serious attempt at mica mining that has been made in the State. The mica occurs as a constituent of a sill-like mass of coarse pegmatite, which dips to the east at about 30°. Its thickness is at least 12 feet, the base not being exposed. Commercial mica is confined to a zone about 5 feet thick in the lowest part of the pegmatite layer as now exposed. Within this 5-foot zone muscovite is estimated to form from 10 to 20 per cent of the material of the pegmatite.

Some of the masses of pure orthoclase feldspar associated with the mica are 5 feet across, but the total quantity present is not sufficient to make it of commercial importance. Intergrowths of quartz and muscovite are common.

The pegmatite contains no biotite and no black tourmaline. The associated rock is a granite gneiss, and both gneiss and pegmatite are intruded by a dike of diabase.

Some of the muscovite books are 1 foot across, but most of them are under 5 inches. The larger plates are invariably cut up by ruling planes into a number of smaller pieces. Much of the mica is worthless for anything but scrap because of the prevalence of ruling, wedge structure, and twinning. Most of the thumb-trimmed material seen by the writer was in pieces 2 or 3 by 3 inches in size. The mine was not being worked at the time of the writer's visit in September, 1906, and although several tons of mica lay in the trimming sheds, the best of the output was reported to have been sold. It was therefore impossible to make a wholly fair estimate of the average value of the mica mined, but the quality of the material is superior to that from any other known locality in Maine and appears to warrant further development.

The property was opened in 1900 and was also worked in 1902 by the Beech Hill Mining Company, who subsequently sold the property to New York persons. About a ton of thumb-trimmed mica was marketed at prices ranging from 8 cents to $1 a pound, and about 10 tons of scrap mica was sold. The remainder of the material quarried was still in the mine buildings at the time of the writer's visit. The equipment includes a steam drill and boiler and a shed where the trimming was done.

SAGADAHOC COUNTY.

GEORGETOWN.

The rocks of Georgetown are mostly sedimentary schists and intruded masses of pegmatite, normal granite, and flow gneiss. The only pegmatite deposit now worked is on the east side of Kennebec River, near its mouth, where feldspar is quarried by Golding's Sons Company, of Trenton, N. J.

Georgetown Center.—The relations between the pegmatite and schists on Bay Point Peninsula (see below) are repeated in good exposures at the four corners west of Georgetown Center. Here a mass of pegmatite 10 feet in maximum width intrudes the schists irregularly, sending off into them an apophysis 1 foot in width at its base, but tapering out within 6 feet. This branch shows the same irregular pegmatitic texture as the larger dike but becomes finer grained as it tapers. The bordering schist contains numerous quartz stringers, some of which are distinctly traceable into the pegmatite and near the latter carry a few mica plates.

On the hill east of the gurnet at Georgetown Center a number of prospect pits for feldspar were opened by J. S. Berry. Black tourmaline and biotite are so abundant in most of the pegmatite as to render it useless for pottery purposes.

Hinckleys Landing.—On the shore, about one-half mile south of Hinckleys Landing, a pegmatite mass in the schist gives off a branch dike 3 to 6 inches wide, which very near where it leaves the parent mass becomes fine grained and typically granitic in texture.

Golding's feldspar quarry.—One of the most productive feldspar quarries in Maine, and one that has been worked intermittently for over thirty years, is located near the east shore of Todds Bay near the mouth of Kennebec River and is now owned and operated by Golding's Sons Company, of Trenton, N. J. It may be reached by a drive of 11 miles from Woolwich or by steamer from Bath to Bay Point Landing, which is only about 1½ miles from the quarry. The Bath quadrangle of the United States Geological Survey includes this area. The property was visited by the writer in July, 1906, and again in November, 1908.

The excavations cover an area of about 3 acres and consist of three open pits. The southernmost pit, which is the oldest and largest, had been abandoned for many years at the time of the writer's visit in 1906, but in 1908 the quarry waste which had been dumped in it was being removed and new excavating had revealed considerable amounts of excellent feldspar. It is significant that much of the waste material dumped into this pit in the early mining is of good commercial grade according to present standards and is being saved. In the early days graphic granite was mostly discarded and only practically pure feldspar utilized. This pit is now about 100 feet in depth. The northernmost pit, from which large amounts of spar have recently been taken, is 200 feet long in a direction N. 25° E., 40 to 75 feet wide, and 20 to 30 feet deep.

In this quarry the commercially valuable rock is mainly a coarse graphic intergrowth of feldspar and quartz, which is estimated to comprise about one-half the total material excavated, the other half being waste which is highly quartzose or contains muscovite or iron-bearing minerals. (See Plate XVIII).

The quartz of this quarry is mostly gray and semiopaque, and in many places has a granular appearance. In a few places it is slightly pinkish in hue. Masses of pure quartz are usually small, the largest observed by the writer being a mass 6 feet across in the northernmost pit. It is not utilized commercially.

Most of the feldspar is orthoclase or microcline with small amounts of albite. The following analysis by the Pittsburg testing laboratory of the United States Geological Survey is of the best grade of buff-colored feldspar:

Analyses of feldspar from Golding's Sons Company quarry.

Silica (SiO_2)	65.23
Alumina (Al_2O_3)	20.09
Iron oxide (Fe_2O_3)	.71
Lime (CaO)	None.
Magnesia (MgO)	None.
Potash (K_2O)	11.60
Soda (Na_2O)	2.00
Loss on ignition	.36
	99.99

Very few large masses of pure feldspar are exposed in the present quarry openings, but it is said that in the past single blasts have loosened 100 tons of almost pure material. In the southern pit a number of masses of pure feldspar several feet across were exposed in 1908, but most of the rock here and practically all exposed in the middle and northern pits is an intergrowth of quartz and feldspar. Most of this intergrowth, however, is of excellent quality for pottery uses, since injurious minerals such as muscovite and black tourmaline are usually confined to certain portions of the mass and can be readily separated from the rest of the rock in mining. Although the graphic form of quartz and feldspar intergrowth is the most common, very perfect dendritic penetrations of feldspar by quartz are also present.

Muscovite is not present in sufficient amounts to be of any commercial importance. All the larger books are of the wedge variety. Graphic intergrowths of quartz and muscovite are also found locally, as are rounded aggregates made up almost entirely of small muscovite crystals and similar to those observed at the G. D. Willes quarry in Topsham.

Biotite is almost entirely absent, but in its stead occurs black tourmaline. The latter is locally very abundant in prismatic crystals, some of which are 2½ to 3 inches in diameter and a foot or more in length. The tourmaline is not evenly distributed through the pegmatite but is confined almost entirely to certain irregular zones which may be avoided or discarded in the quarrying process. It is more abundantly associated with the quartz than with the feldspar.

Garnet occurs in deep flesh-colored crystals, usually small and associated with quartz and muscovite. Some light-green opaque beryl is found, one mass penetrating quartz being 14 inches long and 4 inches in diameter.

The contact of the pegmatite with other rocks is not exposed in any of the quarry openings, but is fairly well shown a few rods northeast of the quarry near the highest part of the same hill, where the bordering rocks are schists which strike slightly east of north and dip nearly vertical. The contact nearly parallels the trend of the schists and the pegmatite is plainly intrusive, locally cutting across the foliation of the schists and sending off broad apophyses into them. A noteworthy feature of this contact is the complete absence of any change in texture or coarseness in the pegmatite as the schist is approached. A coarse aggregate of black tourmaline crystals, some of which are 1¾ inches in diameter, occurs within 2 feet of the contact; and graphic granite of the same coarseness as in the central parts of the pegmatite mass occurs along its border. The schist is a quartz-biotite rock, in many places highly garnetiferous and containing abundant stringers of white to brownish quartz, which, at this point at least, have no traceable connection with the associated pegmatite and are no larger nor more numerous near the contact than some distance away. The schist folia in many places show numerous minor contortions.

The present excavations cover almost the whole area of outcrop of the pegmatite body. Future work will probably consist largely in deepening the present pit, but there is reason to expect that the deposit will continue of good quality and of about the same dimensions to a considerable depth. A number of other dikes of pegmatite of similar size and shape occur in the vicinity and some of them have been worked to a slight extent. None of these, so far as seen, show any large amounts of feldspar of commercial grade.

The rock is excavated by steam drilling and dynamite blasting and in the largest pit is hoisted by derrick and hoisting engine. It is broken up and sorted by hand and hauled by wagon one-fourth mile to the shore, where it is transferred to small sailing barges, which convey it either to vessels for shipment to Trenton by water or up Kennebec River 10 miles to Bath for shipment by rail. About fifteen men are usually employed in this quarry.

Small Point feldspar quarry.—A small feldspar quarry, now abandoned and partly filled with water, is located one-half mile east of the Golding quarry, near the head of Sagadahoc Bay and east of the highway. It is a single pit about 75 feet long, 35 feet wide, and probably 30 to 40 feet in depth, though only 25 feet of wall shows above the water level. The rock is similar in nearly ever respect to that quarried at the Golding quarry, but the area of the deposit seems to be very small, schist occurring within a hundred feet or so north, west, and south of the pit.

Schist-pegmatite contacts on Bay Point Peninsula.—The contacts between the pegmatites and the schists are well exposed at a number of points along the shores of Bay Point Peninsula. A few rods north of the steamboat landing at Bay Point the pegmatite cuts directly across the schist folia, sending off quartz stringers into the schist. The pegmatite shows no noticeable change in texture or composition to a point within about 10 inches of the contact, but from there on tends to become finer grained and less feldspathic, the rock close to the contact being an aggregate of quartz and muscovite. Muscovite also occurs in some of the quartz stringers near their point of departure from the main pegmatite mass. The schist near the pegmatite is rich in dark-brown tourmaline crystals, some of which are one-half inch long and one-eighth inch in diameter; they are probably the results of contact metamorphism.

Although the quartz stringers described above are traceable into the pegmatite, in many other places the pegmatite cuts distinctly across both the folia and quartz stringers of the schist. In such places, although the quartz stringers may not be offshoots of the pegmatite mass immediately associated with them, the absence of genetic connection with other pegmatite of the vicinity is not proved. Such a connection is rendered probable by the presence of some feldspar in a number of the larger quartz lenses. Near the north end of Bay Point Peninsula one quartz lens bearing some feldspar is 1½ feet in greatest width and 3 to 4 feet in length.

The conversion of certain of the schists into injection gneisses through their penetration by pegmatite and quartz stringers proceeding from a larger pegmatite mass is well shown in Plate IV, *B*, reproduced from a photograph taken along the wagon road near the center of Bay Point Peninsula. The large pegmatite mass shown in this picture is quite quartzose, with masses of pure quartz 4 to 5 feet across. The feldspar is in small crystals intergrown with quartz and mica and does not occur in large crystals comparable to the quartz masses. The quartz stringers of the schist are traceable in many instances with perfect continuity into the quartz of the schist, and a number of the quartz stringers contain muscovite crystals. Within 1½ feet of the main pegmatite mass the schist becomes darker colored through the abundant development in it of dark-brown tourmaline.

On the east shore of Kennebec Point, about half a mile northeast of the extreme southern tip, schists are intruded by pegmatitic granite similar in mineral composition to the coarse pegmatite at the Golding quarry, its principal constituents being quartz, potash feldspar, muscovite, and black tourmaline. The average size of grain in this granite is not over one-fourth inch, although some of the feldspars are 3 inches long. None of the black tourmaline crystals are over one-fourth inch and they average only about one-eighth inch in width. It is significant that the minerals, especially the black tourmaline, show a noticeable amount of parallel orientation in certain parts of the ledge, indicating a certain amount of flowing movement during crystallization. The rock becomes finer grained within 8 or 10 inches of the schist contact. This rock gives every indication of being intermediate in its character between normal granite and the typical coarse pegmatite of this region.

TOPSHAM.

The rocks of the town of Topsham are quartz-mica schists which have been intruded by pegmatite, by flow gneisses of granitic composition, and to some extent by granite. Exposures showing the characters and relationships of these rocks are plentiful and excellent.

Distribution of the quarries.—The pegmatites of the town are now worked for feldspar at several points and were once worked at a number of others now abandoned. The quarries all lie within a belt about a mile in width, extending from Mount Ararat, near Topsham village, in a northeasterly direction nearly to the Topsham-Bowdoinham line. Within this belt are eight quarries, only three of which are now active, and a number of prospect pits. It is significant that the line of distribution of these quarries corresponds closely with the trend of the metamorphosed sedimentary schists into which the pegmatites were intruded. Because of the soil covering it is impossible to determine the exact limits of the coarse pegmatite bodies exposed at each of these eight quarries, but it is evident from a study of the rocks between the various quarries that the pegmatite bodies which are worked are not all of them parts of a single pegmatite mass but are more or less detached intrusions in a region where the rocks are mainly schists. Within the belt, however, the pegmatitic intrusions are more numerous and are some of them of coarser texture than in the surrounding country. If we may use the form of the smaller and finer-grained pegmatite masses as an index to that of the larger and coarser ones (which are commercially valuable), the latter are probably, for the most part, somewhat elongate in a direction slightly east of north, parallel to the general trend of the inclosing schists and gneisses.

Products of the quarries.—Feldspar is the only mineral of much commercial importance at any of these quarries. Quartz of excellent quality is present in considerable amounts and is often saved in the quarrying process, though at present finding but slight market. At some of the quarries tourmalines and aquamarines of gem quality are now and then obtained. A description of the quarries in the order of their distribution from southwest to northeast is given below.

Mount Ararat feldspar quarries.—A quarry from which feldspar and quartz have been obtained is situated on the east slope of Mount Ararat, about 1 mile north of Topsham village. The deeper part of the excavation is about 40 feet long from east to west, 10 feet wide, and 12 feet in maximum depth. A shallow excavation adjacent to the northwest part of the deeper pit covers an area of about 20 by 30 feet. The quarry has not been operated for several years.

The lower pit exposes considerable amounts of clean, white, gray, and nearly black semiopaque quartz but shows few masses of pure feldspar more than 3 or 4 inches in diameter. Though feldspar was the principal mineral sought, the quartz was saved in the quarrying process and tons of it are now piled near the pit. The feldspar is cream colored to nearly white and is shown by microscopic examination to be principally microcline, with occasional very small amounts of the white soda feldspar, albite. In the upper and shallower portion of the quarry the amount of pure quartz is less and the amount of pure feldspar is greater than in the lower portion. Some of the masses of pure feldspar there are 3 to 4 feet across. They grade into a coarse graphic intergrowth of quartz and feldspar and the latter into extremely fine graphic granite. Only the pure feldspar and the coarse graphic granite were used commercially. Of the iron-bearing minerals which would injure the quality of the feldspar for pottery purposes, black tourmaline is almost entirely absent and black mica (biotite) is rare. Garnet is rather an abundant constituent, but is associated mainly with the muscovite and with the finer-grained portions of the pegmatite, and only rarely with the more feldspathic parts that are commercially available. Magnetite occurs rarely in small irregular octahedra.

Muscovite or white mica is also an abundant constituent of the pegmatite as exposed in the upper pit. It is pale green to nearly colorless and occurs in books, some of which are 8 to 10 inches in diameter. The great bulk of the muscovite is of the wedge variety and shows twinning; it could be utilized commercially only as scrap mica. A small amount is plate mica and splits readily into sheets, which when trimmed may measure 4 by 5 inches, though mostly smaller. Most of this plate mica incloses between its lamellæ thin branching crystals of magnetite. A few small masses of columbite, generally exhibiting very imperfect crystal forms, are found in the quartz-feldspar masses.

The wall rock of schist or gneiss is nowhere exposed at this quarry, and the soil covering makes it impossible to trace the exact limits of the deposit. If one may judge from neighboring masses of pegmatite whose boundaries are exposed, this mass is probably more or less irregular in outline and somewhat elongate in a direction parallel to the trend of the neighboring schists—that is, somewhat east of north. The deposit does not appear to be very extensive, but the quality is good, and there seems to be warrant for further development work on a small scale.

A second small feldspar quarry, on the northern slope of Mount Ararat, consists of a single hillside pit about 150 feet long, 30 feet in average width, and 20 feet in greatest depth. It was last worked in 1905. The rock is a wholly irregular association of quartz, feldspar, muscovite, biotite, and garnet, with smaller amounts of rarer minerals. The quartz is prevailingly dark gray in color and semiopaque, but in some places is white and in a few nearly black. A number of the pure quartz masses are 3 to 4 feet across; one, flat lying and exposed at the base of one of the quarry walls, is 5 feet in maximum width and 25 feet in length, with very irregular boundaries.

Most of the feldspar is pale pink in color, but certain portions are cream colored, and others decidedly red. Microscopic examination shows that the feldspar belongs mainly to the potash varieties orthoclase and microcline, the former greatly predominating. With these are associated small amounts of the soda feldspar, albite, which is frequently intergrown microscopically with the orthoclase or microcline. Throughout most of the quarry the masses of pure feldspar are not over 4 to 5 inches across, though a few crystals measure 2 to 3 feet. The bulk of the material quarried for pottery use is a graphic intergrowth of feldspar and quartz, most of it coarser than that found at the quarry on the eastern slope of Mount Ararat. The quartz thus intergrown with the feldspar commonly assumes branching or dendritic forms, a characteristic not observed in most of the pegmatite deposits.

Muscovite of the wedge variety occurs sparingly in books up to 6 inches in greatest diameter. No clear plate mica was observed. Of very common occurrence are graphic intergrowths of muscovite and quartz, many single crystals of muscovite with roughly hexagonal outline grading outward into a fringe of graphically intergrown muscovite and quartz. In some places muscovite and feldspar are graphically intergrown. The quartz of these muscovite intergrowths is in many places continuous with quartz intergrown with feldspar.

Biotite is much more abundant than at the quarry on the eastern side of Mount Ararat and dominates over muscovite. It occurs in the characteristic lath-shaped crystals, many of which have a length of 2 feet, a width of 4 to 5 inches, and a thickness of one-half inch to 1 inch. The largest biotite crystal observed was 3½ feet long, 2½ feet wide, and 1 to 2 inches thick. These crystals penetrate the pegmatite mass in every conceivable direction.

Garnet is rather abundant and is generally dark red and submetallic in appearance. In some places it is intergrown with quartz and in others with both quartz and muscovite. One garnet crystal was 2½ inches across. It is most abundant in the finer grained portion of the pegmatite and in those portions rich in muscovite and is rare in the parts which are used commercially. Magnetite occurs only rarely in imperfect octahedra showing step structure.

Schists and gneisses are nowhere exposed in this quarry and near-by outcrops are not numerous, so that it is impossible to determine the form or area of the pegmatite. On the north wall of the quarry a small mass of fine-grained granite showing locally a somewhat gneissic structure is exposed and is intruded by the pegmatite, the latter cutting across the banding of the granite gneiss, though there is crystallographic continuity between the two.

The amount of feldspar of commercial quality now exposed is not large, and the abundance of biotite and garnet render much of the material valueless for pottery uses. The extent of the deposit can not be accurately predicted, but is probably not very great. Further development on a small scale could probably be profitably undertaken and might reveal some good spar not now exposed. The deposit is located 2 miles from the Maine Central Railroad station at Topsham. The nearest point on the railroad is only three-fourths of a mile southeast of this quarry and the one previously described, but there is no wagon road available in this direction.

Fisher's feldspar quarry.—A small quarry not now worked is situated 1¼ miles west-northwest of Cathance station along the northern valley slope of Cathance River. This quarry, which was formerly operated for feldspar by J. A. Fisher, consists of a single pit about 150 feet long from north to south, 20 feet or so in average width, and about 18 feet in maximum depth. It is located on a southern hill slope.

As in most of the other feldspar quarries, there is no regularity in the arrangement of the constituent minerals with the single exception of muscovite, which occurs principally along certain zones which have, however, no definite trend with respect to the general outlines of the deposit.

The quartz is white to gray in color, but no very large masses are exposed.

The feldspar is cream colored and is shown by microscopic examination to be mainly microcline with some orthoclase. Small amounts of the soda feldspar, albite, probably occur as in the other quarries in this vicinity, though none was observed by the writer. One mass of pure feldspar, 3 to 4 feet wide and 10 feet high, exposed on the west wall of the quarry, passes by perfect gradations into a coarse graphic intergrowth with quartz and this in turn into a much finer graphic intergrowth. As in most of the feldspar quarries, the coarse graphic granite forms the bulk of the material mined for pottery purposes. The chemical composition of graphic granites from this quarry is discussed on pages 40, 124, and their appearance is shown in Plate XVIII.

The muscovite, so far as present exposures show, is all of the wedge variety and is mainly confined to certain zones which penetrate the pegmatite irregularly (see Pl. IX, *A*, and p. 26); being localized in this manner, it does not seriously interfere with the feldspar mining. The muscovite books are nearly all characterized by twinning and wedge structure. No plate mica was observed. Graphic intergrowths of quartz and muscovite are common. In some parts of the pegmatite biotite dominates over muscovite; it is usually most abundant in the finer-grained portions.

An examination by Wright and Larsen of the white quartz of the larger quartz areas at this quarry showed that it probably crystallized under low-temperature conditions. Quartz from the coarser phases of the graphic granite was also examined and though the results were not conclusive they indicated that the quartz may have crystallized under high-temperature conditions. Since the areas of pure quartz are closely adjacent to those of graphic granite and indeed grade into them most irregularly, these results suggest that the crystallization temperatures of the pegmatite mass as a whole were not far from the inversion point of quartz (about 575° C.); however, the imperfect character of the data must be borne in mind. This matter is discussed in more detail on pages 36–39.

Outcrops are not numerous enough in the immediate vicinity to determine the extent or form of the pegmatite body. The materials exposed in the present excavation seem to indicate that a considerable supply of spar is still available and seem to warrant further development.

William Willes feldspar quarry.—A small quarry situated 1½ miles northwest of Cathance station and operated by William Willes for the

Trenton Flint and Spar Company was opened early in 1906. It occupies an area of a little more than 1 acre, and its average depth is about 10 feet. Natural drainage is possible at present depth, but further excavation will necessitate pumping. The rock is a wholly irregular association of quartz, feldspar, mica, and rarer minerals.

The quartz is mainly light gray in color and occurs locally in pure masses 5 or 6 feet in diameter. Many even of the larger quartz masses exhibit crystal faces along their contact with other minerals. Quartz is saved in the quarrying process but finds only a very irregular market.

The feldspar is buff colored and is shown by microscopic examination to be mainly orthoclase and microcline. The soda variety, albite, also occurs but forms only a small percentage of the total mass of feldspar; a few crystals of albite are 4 to 5 inches across. As at most of the Maine feldspar quarries, the great bulk of the material quarried for pottery purposes is a coarse graphic intergrowth of quartz with potash feldspar. In the northern part of the quarry a mass of pure feldspar 10 feet across is exposed on a glaciated surface.

Muscovite occurs in grapihc intergrowth with quartz and also in books, the latter being mostly wedge mica. Some of these books are 10 inches across. The total amount of muscovite present is not sufficient to make it worth while to save it in quarrying.

Biotite is about equally as abundant as muscovite and occurs in characteristic lath-shaped crystals; one of these was 4 feet long, 8 inches wide, and 1 inch thick. Much of the biotite is decomposed to what appears to be chlorite colored with hematite.

Garnet is moderately abundant, usually occurring in compound crystals of dark-red color with submetallic luster.

Beryl is moderately abundant, some hexagonal crystals being 10 inches in diameter. Some of the smaller crystals are partly transparent and have been sold to mineral collectors.

Some columbite is found in small imperfectly developed crystals but is not sufficiently abundant to be of commercial consequence.

In one place in the quarry a small amount of hornblendic granite gneiss occurs. The pegmatite cuts across the foliation of the granite gneiss and is plainly somewhat the younger. Its exact attitude and boundaries could not be determined because of the scarcity of outcrops in the vicinity, but it is probable that further stripping near the present workings will reveal considerable amounts of commercially valuable spar.

At the time of the writer's visit seven laborers were employed in the quarry besides the foreman and the superintendent. The rock is hauled by two 2-horse teams a distance of 1¼ miles to the feldspar mill near Cathance station.

Maine Feldspar Company's quarry.—A small feldspar quarry a few rods southeast of the one just described was opened in 1906 by the Maine Feldspar Company, of Auburn, Me. The rock, which is similar in every way to that at the William Willes quarry, is hauled by team about 1¼ miles to Cathance station and from there shipped by rail to the Maine Feldspar Company's mill at Littlefield, 3 miles southwest of Auburn.

G. D. Willes feldspar quarry.—A feldspar quarry operated for the Trenton Flint and Spar Company by G. D. Willes, of Brunswick, is situated about 2 miles northwest of Cathance station and is the oldest and by far the largest of the Topsham quarries. Its irregular opening covers several acres and the material is excavated from several levels, the greatest depth being about 50 feet.

Although the great bulk of the commercial spar now taken from this quarry is a coarse graphic intergrowth of feldspar and quartz, masses of pure quartz and of pure feldspar occur which are larger than those seen at any other quarry in the State. A single mass of pure white quartz in the northern part of the quarry is 50 feet long and is exposed for a height of 10 feet. The pegmatite is in general coarser at the northern than at the southern end of the quarry.

The feldspar also occurs here and there in crystals of large size, one in the northern part of the quarry measuring 15 feet across. The bulk of the feldspar, as shown by microscopic study, belongs to the potash varieties orthoclase and microcline, but some small masses, not many of them more than a few inches across, are of the white soda feldspar, albite.

On the wall at the extreme southern end of the quarry certain portions of the pegmatite up to a foot or so in width are a micrographic granite and exhibit the peculiar structure described on page 123.

Muscovite is concentrated along certain belts traversing the pegmatite mass in various directions. Their general form is similar to that shown in Plate IX, *A*. The central portions for a width of a few inches consist of an aggregate of heterogeneously disposed muscovite plates, few of them over one-fourth inch in diameter. From this finer-grained portion spearhead-shaped books of muscovite, some of them a foot in length, showing wedge structure, project in a direction nearly at right angles to the general plane of the mica belt. In the southern part of the quarry muscovite occurs also in nearly equidimensional aggregates, in some places 5 feet across, made up of small, heterogeneously arranged plates averaging about one-fourth inch across. From their borders these muscovite aggregates send off spearhead-shaped books of muscovite into the surrounding quartz, feldspar, and graphic granite. Some graphic intergrowths of quartz and muscovite occur, but they are not abundant. Under present conditions it would probably not pay to save as scrap mica the muscovite. obtained in the feldspar mining. No plate mica was observed.

Biotite is moderately abundant in certain parts of the pegmatite. It penetrates the feldspar and quartz in lath-shaped masses, the largest of which was 2 yards long by 3 inches wide and one-fourth inch thick.

As in most other feldspar quarries, small garnets are abundant only in certain portions of the deposit, the coarser graphic granite and the pure feldspar being almost entirely free from them, and they are not seriously injurious to the commercial value of the deposit.

Cavities up to 1 foot in diameter and of various form are rather a constant feature of the coarser portions of the pegmatite in the northern part of the quarry. They may occur within the areas of pure quartz or feldspar, on the border between quartz and feldspar masses, or more rarely in the coarse graphic granite. Usually they contain groups of somewhat smoky semitransparent quartz crystals, some of which make handsome cabinet specimens. In a few, transparent green tourmalines and aquamarines (beryl) of gem quality have been found.

The schists and gneisses which border the pegmatite are exposed at the southern end of the quarry, where they show evidence of much softening as a result of the pegmatite intrusion. In general they are rather flat lying. Probably the pegmatite mass is also in general somewhat flat lying, though very irregular. It is probable that the workable pegmatite does not extend southward much beyond the limits of the present pit, but northward it is known to extend into property said to be controlled by the Maine Feldspar Company. Here it has been worked in the past from a number of small openings and very considerable amounts of commercial spar are still available.

The methods of operation at this quarry are somewhat antiquated for a working of this size, the drilling all being done by hand and the blasting by black powder. A tramway carries the waste to dump piles and the good rock to stock sheds, from which it is loaded into wagons and hauled 1¾ miles to the mill near Cathance station (p. 18).

North Topsham feldspar quarry.—A feldspar quarry in the northern part of the town of Topsham, one-half mile west of Cathance River and 1 mile south of the Topsham-Bowdoinham line, was formerly operated by the Trenton Flint and Spar Company, the rock being hauled by team 2 miles to the mill near Cathance station. The quarry is located on the western valley slope of the river and is an irregular opening extending north and south along the hill slope for about 200 feet and extending into the hill for about 40 feet. There is a complete absence of any regularity in the arrangements of the pegmatite constituents.

The quartz is prevailingly white or light gray, though smoky in some places.

The feldspar is white to cream colored, and is shown by microscopic examination to be mainly orthoclase, with small amounts of albite and microcline. The albite in many places forms a fine microscopic intergrowth (microperthite) with the orthoclase. Some pure feldspar masses measure 4 to 5 feet in diameter, but the bulk of the material quarried for pottery purposes was a graphic intergrowth of quartz and feldspar.

Muscovite, mostly pale green in color, is generally graphically intergrown with quartz, though a few books of clean mica up to 5 or 6 inches in diameter occur. These are all, so far as observed, of the wedge variety, and the quantity is so small that it would be hardly worth while to save them for scrap mica.

Biotite is not very abundant in any part of the quarry and in some parts is wholly absent. Where it occurs it forms thin lath-shaped crystals averaging about 6 inches long, 1 inch wide, and one-fourth inch thick.

Garnet is absent from much of the pegmatite but locally is abundant in the finer-grained portions in crystals from one-sixteenth to one-fourth inch in diameter. Very rarely a crystal measuring 3 inches is found, and in these the garnet is usually graphically intergrown with quartz. The color ranges from pink to deep red, with submetallic luster.

The area and form of this pegmatite body could not be determined because of the scarcity of outcrops in the vicinity of the quarry, but the occurrence at short distances east and west of small masses of pegmatite of commercial grade seems to indicate that the deposit may extend considerably beyond the area now exposed.

The quantity of material in sight and the freedom of most of the material from iron-bearing minerals favors further development.

Mill of the Trenton Flint and Spar Company.—The feldspar mill of the Trenton Flint and Spar Company is located on Cathance River about one-half mile north of Cathance station. During high water it utilizes the water power of this small river, but it is also provided with steam power. Its equipment consists of three chaser mills and four ball mills of the usual types. The grinding process is that described on page 127. The capacity of the mill is about 16 tons in twenty-four hours, the ground spar being hauled by wagons for one-half mile from the mill to Cathance station, on the Maine Central Railroad, where it is loaded for shipment.

Vicinity of Topsham village.—At a small road-metal quarry on the west slope of Mount Ararat the dominant rock type is a hornblende granite schist of regular and well-marked foliation. It strikes, in the main, about N. 35° E. and dips 50° SE. In both megascopic and microscopic appearance it is practically identical with the lighter phases of the schist from the road-metal quarry in Brunswick village (p. 61). As at that quarry, dominant acidic bands of schist, prevailingly pink or gray in tone, alternate with smaller amounts of dark-gray bands of quartz diorite and other nearly black bands of diorite schist. Under the microscope these schists show no cataclastic structures; they owe their foliated structure to parallel elongation of the hornblende grains and to some extent also of the grains of biotite and quartz. Nothing either in their texture or their composition indicates that they are not primary-flow gneisses.

Both in the lighter and darker phases of the schist, but much more abundantly in the lighter, are coarser bands of pegmatitic texture, consisting mainly of quartz and feldspar, with some biotite and magnetite. Many of these are parallel to the foliation of the schist and are of even width and uniform character for several yards. Others, especially the larger masses, cut distinctly across the schist folia, the contact being sharp and without suggestion of absorption.

An interesting feature of some of the pegmatite bands which parallel the foliation of the schists is the presence in them of a slight foliation parallel to that of the inclosing schist. As in the schist, this foliation is defined by bands richer than the bordering portions in hornblende and biotite. In one place a faint foliation is perceptible in the center of a pegmatite mass 1½ feet wide that cuts across the foliation of the schists. It does not parallel the trend of the dike but does parallel the foliation of the inclosing schist and is defined by the arrangement of the quartz in elongate and somewhat irregular bands. As there is no evidence of appreciable absorption of the schist by the pegmatite magma, and also no evidence of metamorphism subsequent to the intrusion of the pegmatite, such foliation in the pegmatite is strongly suggestive of parallel flowing movements in the schist and in some of the pegmatite. The field and microscopic evidence on the whole favors the conception that the schists are of primary or flow-igneous origin, and that some of the pegmatite was crystallizing before flowage had entirely ceased in the bordering schist, but that other portions of the pegmatite were intruded after the schist had completely solidified. The practical identity in mineral character between the different masses of pegmatite at this quarry suggests that the distinctly intrusive portions were only slightly later crystallizations than their host and that all the pegmatite had the same magmatic source.

One of the largest masses of graphic granite observed was on the west slope of the 180-foot hill in the sharp bend of Androscoggin River just west of Brunswick. The ledge, which is in plain sight from the railroad track, is 150 feet long and averages 25 feet wide.

Practically this whole mass is a graphic intergrowth of quartz, with white to pale pink orthoclase and microcline. Some of the feldspar crystals of this intergrowth are shown by reflections from their cleavage faces to be 2½ feet across. The coarseness varies rapidly from point to point even within the range of a single feldspar individual. At the south end of the outcrop the graphic granite grades into pegmatite of irregular texture, showing some masses of pure feldspar 2 to 3 inches across. Both the graphic granite and this irregular-textured pegmatite inclose scattered biotite laths.

At the south end of this exposure also there is some associated gray gneiss. In one place the pegmatite cuts directly across the folia of the gneiss. In other places graphic granite forms knots or short lenses up to 6 inches in width between the gneiss folia. The mass of graphic granite exposed in this ledge is the largest continuous mass observed by the writer in the State.

ECONOMICALLY IMPORTANT PEGMATITE MINERALS.

FELDSPAR.

The feldspars are compounds of alumina and silica with one or more of the bases potash, soda, and lime; rarely barium is present. They fall into two principal groups, the potash-soda feldspars and the lime-soda feldspars, both of which may be present in the same deposit or even intergrown in the same crystal.

POTASH-SODA FELDSPARS.

The principal representatives of the potash-soda feldspar group are orthoclase and microcline, both of which have the composition $KAlSi_3O_8$ or $K_2O.Al_2O_3.6SiO_2$. These two varieties have also the same crystal form and are similar in most of their physical properties. For commercial purposes they may be regarded as identical, for they can not be distinguished from each other with the unaided eye and are often associated in the same crystal. The theoretical percentage composition of pure orthoclase or microcline is silica (SiO_2), 64.7 per cent; alumina (Al_2O_3), 18.4 per cent; and potash (K_2O), 16.9 per cent. Soda may partly or completely replace potash in these feldspars. If it is more abundant than the potash, the feldspar is called anorthoclase.

The feldspar of the potash-soda group mined in the United States is mostly pale flesh colored to nearly white, though that from Bedford, N. Y., is reddish and that from near Batchellerville, N. Y., is pearl gray. The potash spars from Norway and from Bedford, Ontario, are reddish in color. The cause of the reddish color is not definitely known, but in some feldspars it seems to be due to the presence of small quantities of finely divided iron oxide. The percentage of iron oxide is smaller, however, in many pink feldspars than in those of lighter color. All the pink spars burn perfectly white, and the iron content is too small to be in the least detrimental in pottery manufacture. Fresh feldspar is so hard that only with difficulty can it be scratched with a knife blade.

As found in the quarries, the potash-soda feldspars seldom show true crystal faces, but when undecomposed break readily into angular pieces, bounded in part by smooth cleavage faces. There are three directions of cleavage, intersecting at definite angles, which are practically identical in orthoclase and microcline and are only slightly different in the soda-bearing feldspars of this group. Only two of the cleavages are well defined, and these invariably intersect approximately at right angles. Both of these principal cleavage surfaces show a high luster, comparable to that exhibited by a plate of glass, though one cleavage face is a trifle less brilliant than the other. The hardness and the two lustrous cleavage planes intersecting at right angles are usually sufficient to identify a mineral as belonging to the group of potash-soda feldspars.

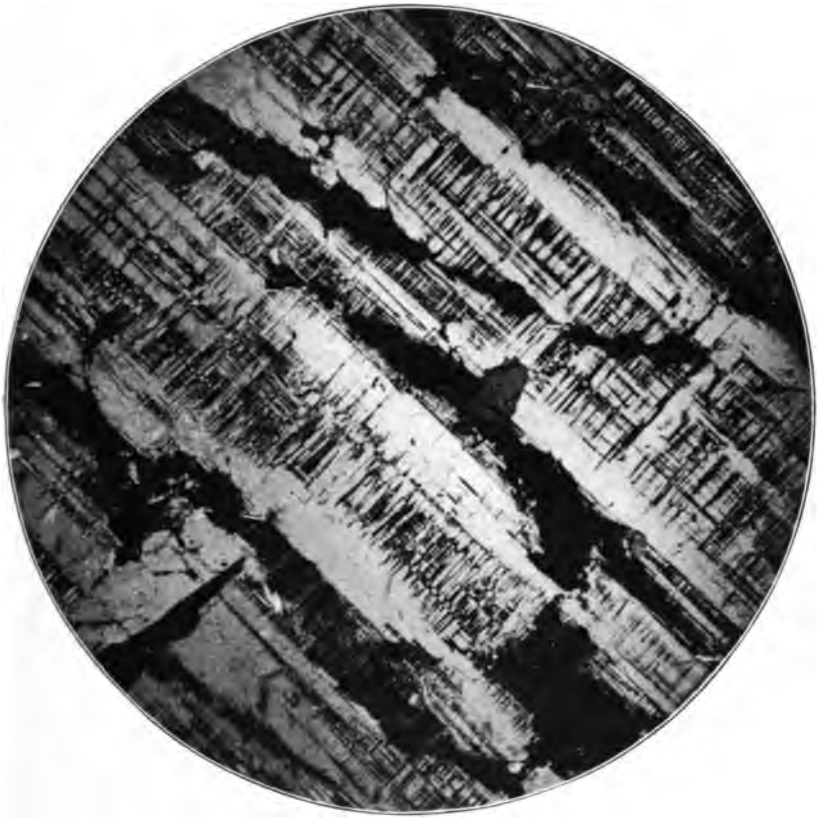
Recent experiments have shown that the potash-rich feldspars have no definite melting point, as metals have, for example. Fusion tests made on finely powdered microcline in the geophysical laboratory of the Carnegie Institution [a] showed that at 1,000° C. traces of sintering were evident; at 1,075° the powder had formed a solid cake; at 1,150° this cake had softened somewhat; and at 1,300° it had become a viscous liquid which could be drawn out into glassy threads. In most of the determinations complete fusion has taken place in the dry state at temperatures below Seger cone No. 9, which fuses at 1,310° C., or 2,390° F.

The great bulk of the feldspar quarried in the eastern United States and in Canada belongs to the class described above, being orthoclase or microcline or an intergrowth of the two. In most quarries this is associated with minor quantities of soda feldspar—albite or oligoclase—occurring either in separate crystals or delicately intergrown with the potash feldspar, as shown in Plate XVII. The presence of the soda spar renders the ground product slightly more fusible. The specific gravity of orthoclase and microcline varies from 2.54 to 2.56.

LIME-SODA FELDSPARS OR PLAGIOCLASES.

The lime-soda group of feldspars, the plagioclases, as they are called, form a continuous series ranging from pure soda feldspar, albite, at one end to pure lime feldspar, anorthite, at the other end. The chemical composition of albite is represented by the formula $NaAlSi_3O_8$ (designated Ab) or $Na_2O.Al_2O_3.6SiO_2$, being similar to that

[a] Day, A. L., and Allen, E. T., The isomorphism and thermal properties of the feldspars: Pub. 31 Carnegie Inst. of Washington, 1905, pp. 13-75; also Am. Jour. Sci., 4th ser., vol. 19, 1905, pp. 93-142.



MICROPHOTOGRAPH OF THIN SECTION OF FELDSPAR FROM QUARRY OF GOLDING'S SONS COMPANY, GEORGETOWN, MAINE. MAGNIFIED ABOUT 40 DIAMETERS.

Showing perthitic intergrowth of potash and soda feldspar characteristic of many commercial feldspars. The lighter portions with striæ crossing at right angles are potash feldspar (microcline). The darker portions with striations in only one direction are soda feldspar (albite).

of orthoclase, except that soda is present in place of potash. The composition of anorthite is represented by the formula $CaAl_2Si_2O_8$ (designated An) or $CaO.Al_2O_3.2SiO_2$. The intermediate members of this feldspar series are mixtures in varying proportions of the two molecules Ab and An and have been divided arbitrarily, as shown in the following table:

Lime-soda series of feldspars.

Albite	Ab_1An_0 to Ab_6An_1	Labradorite	Ab_1An_1 to Ab_1An_3
Oligoclase	Ab_6An_1 to Ab_3An_1	Bytownite	Ab_1An_3 to Ab_1An_6
Andesine	Ab_3An_1 to Ab_1An_1	Anorthite	Ab_1An_6 to Ab_0An_1

The following table shows the percentages of the various oxides corresponding to each feldspar variety:

Percentage weights of the oxides in the feldspars in the lime-soda series.

	SiO_2.	Al_2O_3.	Na_2O.	CaO.
Albite, $Ab_1 An_0$	68.7	19.5	11.8	0.0
$Ab_6 An_1$	64.9	22.1	10.0	3.0
$Ab_3 An_1$	62.0	24.0	8.7	5.3
$Ab_1 An_1$	55.6	28.3	5.7	10.4
$Ab_1 An_3$	49.3	32.6	2.8	15.3
$Ab_1 An_6$	46.6	34.4	1.6	17.4
Anorthite, $Ab_0 An_1$	43.2	36.7	.0	20.1

The field and microscopic studies made by the writer and the few analyses available indicate that most of the plagioclase present in feldspar deposits worked for pottery purposes belongs to the sodic varieties, albite or oligoclase, though the more calcic varieties are probably also present in minor amounts in a few localities. In color the albite and oligoclase range from pure white to pale green. In their commonest forms they show, as do the feldspars of the potash-soda group, two principal cleavage faces with brilliant luster, but these intersect not at 90°, as in orthoclase and microcline, but at about 86°. This difference in angle is not readily recognizable without careful measurements, and in the field albite and other lime-soda feldspars are most readily distinguished from the potash-soda feldspars by the presence in them of faint, perfectly straight striations on the most brilliant of the cleavage faces. These are the result of repeated twinning of the crystal and are best seen by holding the crystal in the sunlight so as to catch the reflection from the principal cleavage face. By turning the crystal slightly one way or another the striations, if present, are readily recognized.

Pure soda feldspar, or albite ($NaAlSi_3O_8$, designated Ab), like potash feldspar, has no definite melting point but, as shown by Day and Allen,[a] melts at temperatures having a range of 150° C. or more, certain portions of a crystal persisting solid while other portions are

[a] Day, A. L., and Allen, E. T., loc. cit.

fluid. Melting in a piece of natural albite was observed to begin below 1,200° C. and was not complete at 1,250°. Complete fusion takes place in albite at a somewhat lower temperature than in orthoclase and microcline. Hence in the manufacture of pottery a glaze prepared with albite will become fluid and will run at a kiln temperature at which a potash-feldspar glaze remains more viscous and yields good results.

The feldspars of this class that contain notable amounts of calcium have fairly well defined melting points. These melting points, as determined by Day and Allen,[a] are given below, with the determinations of their specific gravity:

Melting temperature and specific gravity of lime-soda feldspars.

	Melting temperature (° C.).	Specific gravity of crystalline form.
Albite, Ab_1 An_0	....	2.605
Ab_3 An_1	1,340	2.649
Ab_2 An_1	1,367	2.660
Ab_1 An_1	1,419	2.679
Ab_1 An_2	1,463	2.710
Ab_1 An_5	1,500	2.733
Anorthite, Ab_0 An_1	1,532	2.765

As shown in this table the melting points become progressively higher and the minerals become heavier with increase in the percentage of calcium.

If a melt composed solely of the constituents of pure potash feldspar or pure soda feldspar is allowed to cool the result is invariably a glass; a crystalline product has not yet been obtained in this way. If, however, melts of the lime-rich feldspars are cooled, partial or complete crystallization usually takes place. It is this property of cooling to a glass that renders the potash and soda rich feldspars serviceable for use in making glazes for pottery and enamelware. The crystallization that takes place in the lime-rich feldspars under similar conditions makes them worthless, or at least much less desirable, for these uses.

The following analyses show the chemical characters of typical feldspars that are used commercially. Most of the specimens of crude material analyzed were especially selected for their purity and are not typical of the material in commercial use. Nos. 5 and 6, however, are analyses of specimens of ground "spar" collected by the writer personally from the bins at feldspar mills and represent materials in actual commercial use.

[a] Day, A. L., and Allen, E. T., loc. cit.

Analyses of feldspars.

	Selected specimens of crude feldspar.				Commercial specimens of ground feldspar.	
	1.	2.	3.	4.	5.	6.
Silica (SiO_2)	64 7	64.98	66.23	65.95	76.37	65.87
Alumina (Al_2O_3)	18 4	19.18	18.77	18.00	[a]13.87	[a]19.10
Ferric oxide (Fe_2O_3)	....	.33	Trace.	.12	....	....
Lime (CaO)	....	Trace.	.31	1.05	.26	.20
Magnesia (MgO)	....	.25	None.	Trace.	None.	None.
Potash (K_2O)	16.9	12.79	12.09	12.13	5.24	12.24
Soda (Na_2O)	....	2.32	3.11	2.11	3.74	2.56
Water (H_2O)	....	....	....	....	.30	.64
Loss on ignition	....	.48	....	....	....	....
	100.0	100 33	100.51	99.36	99.78	100.61

[a] Includes trace of iron and any TiO_2 and P_2O_5 that may be present.

1. Theoretical composition of pure orthoclase or microcline.
2. Specimen of crude Norwegian potash feldspar, probably with some intergrown soda feldspar (albite). Used at the Royal Porcelain Works at Charlottenburg, Sweden.
3. Crude pink orthoclase-microcline feldspar, evidently intergrown with some soda feldspar (albite). From feldspar quarry of Richardson & Sons, Bedford, Ontario. Analysis by J. B. Cochrane, Royal Military College, Kingston, Ontario.
4. Crude pink potash feldspar; microcline intergrown with small amounts of soda feldspar (albite). From feldspar quarry of P. H. Kinkles's Sons, Bedford, Westchester County, N. Y. Analyses made for John C. Wiarda & Co.
5. Ground commercial feldspar from Kinkles's quarry, Bedford, N. Y.; so-called No. 3 grade; used in glass manufacture but not for pottery. Sample taken by writer from bins at mill of P. H. Kinkles's Sons. Analysis by George Steiger, in laboratory of United States Geological Survey.
6. Ground commercial feldspar from quarry of J. B. Richardson & Sons, Bedford, Ontario, No. 1 grade. Sample taken by writer from bins at mill of Eureka Flint and Spar Company, Trenton, N. J. Analysis by George Steiger, in laboratory of United States Geological Survey.

The approximate mineral composition of the samples of the commercial ground feldspars (Nos. 5 and 6), as computed from the analyses, is as follows:

Approximate mineral composition of feldspars Nos. 5 and 6, above.

	5.	6.
Quartz (SiO_2)	34.37	3.84
Potash feldspar (microcline or orthoclase) ($KAlSi_3O_8$)	30.58	72.28
Soda feldspar (albite), containing some lime ($NaAlSi_3O_8$ and $CaAl_2Si_2O_8$)	32.83	22.59
Moisture (H_2O)	.30	.64
Other constituents	1.63	1.22
	99.72	100.57

Samples Nos. 5 and 6 may be taken to represent, so far as the percentage of quartz is concerned, the two extremes among potash "spars" in commercial use. No. 5 is much richer in quartz and in soda feldspar than the higher grades from this same quarry and is suitable only for use in glass making, for enamel ware, and for like uses. No. 6 is the best grade of Canadian spar, which is almost free from quartz and brings as high a price as any spar on the market. The bulk of the No. 2 grade or standard spar that is on the market is intermediate in its percentage of quartz between samples 5 and 6, the percentage in most of it being between 15 and 25 per cent.

GRAPHIC GRANITE.

Much of the quartz and feldspar of certain pegmatite deposits is regularly intergrown in the form of graphic granite. (See Pl. XVIII and p. 22.) At the majority of feldspar quarries most of the material shipped is graphic granite, though whatever pure feldspar occurs is usually also included and serves to raise the percentage of feldspar in the whole mass. Analyses of four specimens of graphic granite are given below. These analyses were made by George Steiger in the laboratory of the United States Geological Survey.

Analyses of graphic granite.

	1.	2.	3.	4.
SiO_2	73.89	73.92	72.76	71.00
Al_2O_3	13.75	14.26	[a] 15.47	[a] 16.31
Fe_2O_3, FeO	.26	.30	....	....
MgO	None.	None.	None.	None.
CaO	None.	None.	.19	.22
Na_2O	2.10	2.06	2.35	3.44
K_2O	9.00	8.99	9.28	8.66
H_2O	.24	.11	.15	.12
	99.24	99.64	100.20	99.75

[a] Includes trace of iron and any TiO_2 and P_2O_5 that may be present.

1. Coarse graphic granite from Fisher's feldspar quarry (abandoned), Topsham, Me. Trace of P_2O_5. The quartz layers in this specimen average about 0.1 inch and the feldspar layers 0.4 inch across. The feldspar is cream-colored potash feldspar (microcline), finely (perthitically) intergrown with smaller amounts of soda feldspar (albite).

2. Moderately coarse graphic granite from Fisher's feldspar quarry (abandoned), Topsham, Me. Grades into No. 1. Trace of P_2O_5. The quartz layers in this specimen average about 0.05 inch across and the feldspar layers about 0.15 inch across. The feldspars are of the same character as in No. 1.

3. Fine-grained graphic granite from Kinkles' feldspar quarry, Bedford, Westchester County, N. Y. The quartz layers in this specimen average about 0.03 inch across and the feldspar layers about 0.08 inch across. The feldspars are pale pink microcline finely intergrown with smaller amounts of soda feldspar (albite), containing a little lime.

4. Graphic granite from Andrews quarry, Portland, Conn., varying in coarseness, but all extremely fine grained. The quartz layers in this specimen average not more than 0.02 of an inch across and the feldspar layers not more than 0.05 inch across. Some small areas of pure feldspar were associated with the graphic granite in this specimen, so that the silica percentage shown in the analysis is lower than it would be for graphic granite alone of this fineness. The feldspars are white potash feldspar (microcline), intergrown with smaller amounts of soda feldspar (albite), containing a little lime.

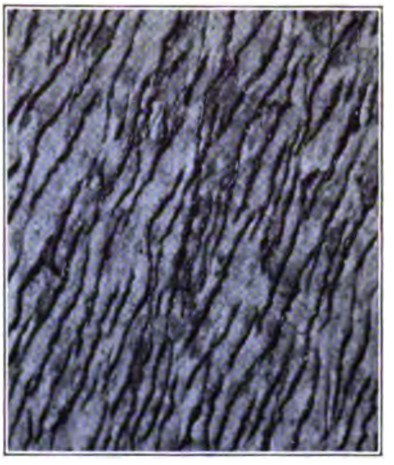
If allowance is made for the water present and the proportion of quartz to feldspars calculated from the above analyses, the results are as follows:

Proportions of quartz and feldspar in graphic granites Nos. 1 to 4 above.

	1.	2.	3.	4.
Quartz (SiO_2)	27.13	26.26	22.94	17.65
Potash feldspar (microcline) ($KAlSi_3O_8$)	54.42	55.22	54.95	51.37
Soda feldspar (albite) with small amounts of lime feldspar in Nos. 3 and 4 ($NaAlSi_3O_8$,$CaAl_2Si_2O_8$)	18.45	18.52	20.99	30.05
Other constituents	Trace.	Trace.	1.12	.92
	100.00	100.00	100.00	99.99

NOTE.—Nos. 1 and 2, representing graphic granite from Fisher's quarry in Topsham, Me., show practically identical proportions between the quartz and the feldspar, although No. 2 is more than twice as coarse as No. 1. In No. 3, from Bedford, N. Y., soda-lime feldspar is more abundant than in Nos. 1 and 2, and the proportion of quartz is slightly less. In No. 4 some pure feldspar is associated with the graphic intergrowth of feldspar and quartz, so that the proportion of quartz in the whole specimen is lower than in any of the other samples.

A



B

C

INTERGROWTHS OF FELDSPAR AND QUARTZ. SHOWING CHARACTERISTIC GRAPHIC GRANITE STRUCTURE. NATURAL SIZE.

A, Graphic granite from Bedford, N. Y. *B*, Fine graphic granite from Topsham, Maine. *C*, Coarse graphic granite from Topsham, Maine.

A graphic intergrowth of potash feldspar and quartz from Elfkarleö, Sweden, which was so fine grained that the graphic structure could be seen only under the microscope, showed on analysis about 79.2 per cent of feldspar and 20.8 per cent of quartz. From the analyses given above and from numerous others which have been published the conclusion seems justified that the proportion of feldspar to quartz in graphic granites, though varying somewhat according to the composition of the feldspars, is nevertheless fairly constant and is not dependent on coarseness of grain. This fact is of practical importance, for a large proportion of the commercial "spar" produced is graphic granite, and it has been the practice at some quarries to discard the finer-grained varieties on the supposition that they contained a larger percentage of quartz than the coarser kinds. Such mining practice is unwarranted, the fine graphic granite being as desirable as the coarse, though both should be mixed with a certain amount of pure feldspar in order to reduce the percentage of quartz in the ground product to between 15 and 20 per cent for the standard grade, as shown by analyses 3 and 4 of the table above.

As in most pegmatite bodies there is very little regularity in the distribution of the different minerals (see p. 22), a deposit that is of excellent quality commercially as regards feldspar may grade within a short distance and in a wholly irregular manner into pegmatite that is worthless because of its large percentage of quartz or its abundance of biotite, black tourmaline, or garnet.

MINING.

The methods of mining feldspar are very simple. The excavations are nearly all open pits, most of them of rather irregular form, the valueless portions of the pegmatite being avoided wherever it is possible in mining. In a few Pennsylvania quarries where the pegmatite masses are rather flat lying and are overlain by a roof of worthless rock short tunnels have been driven from the open pits.

In Maine, Connecticut, and New York the pegmatite is usually firm and undecomposed, even in the surface outcrops, and it is necessary to sink drill holes and blast out most of the material. In Pennsylvania and Maryland, however, most of the pegmatite is much decayed at the surface and can be excavated with picks, shovels, and crowbars. In a few of these quarries kaolin produced by the decay of the feldspar has been found in the past in sufficient quantities to be of commercial importance, though none is now produced. This difference in the character of the pegmatite deposits in the two regions is due to the fact that the Pennsylvania-Maryland region is unglaciated, whereas in the more northerly region glacial ice has planed off most of the products of rock decay.

In some of the smaller quarries, where the rock is firm, drilling is done by hand, but in most of the larger quarries steam drills are used. The large masses are then broken with sledges into pieces 6 inches or less in size. If the material is to be used as poultry grit or for the manufacture of roofing materials no sorting is necessary, but material used for making pottery is hand-picked at the quarry to remove the more micaceous and quartzose parts and the portions carrying iron-bearing minerals. In most of the Pennsylvania and Maryland quarries where the weathered materials near the surface can be excavated with pick and shovel, screening or even washing may be necessary to free the spar from dirt. In some of the larger and deeper quarries derricks and drags are used in hoisting the spar to the surface, the material being then loaded into wagons and hauled either to the railroad for shipment or to the mills for grinding. In some quarries the wagons descend into the pit along an inclined roadway. At two important quarries wire tramways connect quarry with mill.

The cost of actual mining at most of the quarries producing feldspar of pottery grade is reported at from $2 to $2.50 per long ton. At certain quarries where pegmatite is quarried for ready roofing, poultry grit, etc., where cobbling and hand sorting are unnecessary, and where the work is conducted on a large scale, the cost may be as low as 50 cents per ton. Hauling by team from mine to mill or shipping point in most of the feldspar districts may, under ordinary conditions, be estimated at a contract price of 35 to 40 cents per long ton per mile.

COMMERCIAL AVAILABILITY OF DEPOSITS.

Whether it will pay to work a given feldspar deposit depends upon a number of factors, chief among which are (1) the distance from the railroad or navigable water, (2) the freight rates to principal markets, (3) the quantity and quality of the material available, (4) the cheapness with which the feldspar can be mined, and (5) the market conditions. Favorable conditions with respect to some of these factors may offset unfavorable conditions with respect to others. The principal markets for the better grades of feldspar are the great pottery centers—Trenton, N. J., and East Liverpool, Ohio—so that the mines of Connecticut, Pennsylvania, and Maryland have the advantage over those in Maine and northern New York of being much closer to these markets. This superiority in position makes wagon hauls of 6 or 8 miles from mine to shipping point permissible in the Middle Atlantic States, whereas in Maine or in the Adirondack region only a much shorter haul allows a fair degree of profit. Pegmatite sold for roofing or poultry grit commands prices so small that hauls of more than 1 or 2 miles from mine to shipping point would in most places be prohibitive. The freight rates on feldspar from a number of the quarrying districts to Trenton, the principal feldspar milling center, are given below:

Freight rates per hundredweight on feldspar for carloads having a minimum weight of 40,000 pounds, May, 1909.

Bath, Me., to Trenton, N. J.	$0.15
Cathance, Me., to Trenton, N. J.	.17
Auburn, Me., to Trenton, N. J.	.16

The requirements of the potter's trade demand that in general the percentage of free quartz associated with the feldspar used shall not exceed 20 per cent in the ground product, and certain potters demand a spar which is nearly pure, containing probably less than 5 per cent of free quartz. In order to be profitably worked, in most feldspar mines between one-fourth and one-half of the total material excavated should contain less than 20 per cent of free quartz. Freshness of the feldspar is not essential.

A factor of the utmost importance in the mining of pottery spar is the quantity of iron-bearing minerals (black mica, hornblende, garnet, or black tourmaline) which is present and the manner in which these minerals are associated with the feldspar. The requirements of the pottery trade demand that the spar be nearly free from these minerals, which if present produce, upon firing, brown discolorations in white wares. In order that a deposit may be profitably worked, these minerals, if present in any appreciable quantity, must be so segregated in certain portions of the deposit that they can be separated from the spar without much more hand sorting and cobbing than is necessary in the separation of the highly feldspathic material from that which is highly quartzose or rich in muscovite. A number of pegmatite deposits of coarse grain are rendered worthless for pottery purposes by the abundance of one or more of these iron-bearing minerals. The presence here and there of minute flakes of white mica (muscovite) is characteristic even of the highest grades of commercial feldspar, and chemically this mineral is not injurious. It is, however, exceedingly difficult to pulverize the thin, flexible mica plates to a fineness equal to that attained by the feldspar, and it is therefore necessary in mining to separate carefully as much of the muscovite as possible from the spar.

Operation on a large scale with the aid of modern machinery reduces the mining cost. Favorable topographic position—a situation, for instance, that will permit the material to be excavated from a hillside opening instead of being hoisted from a pit—also reduces the cost.

MILLING.

The methods used for grinding feldspar for pottery, enamel ware, etc., are similar in a general way in all of the Eastern States and are very simple. The soda spar quarried in southeastern Pennsylvania is first burned in kilns, which serves to fracture it and thus to facilitate grinding. Most feldspar, however, is fed just as it comes from the quarry into a chaser mill consisting of two buhrstone wheels, 3 to 5 feet in diameter and 1 to 1½ feet thick, attached to each other by a horizontal axle, as are the wheels of a cart. The horizontal axle is attached at its center to a rotating vertical shaft, which causes the buhrstone wheels to travel over a buhrstone bed, the feldspar being crushed between the wheels and the bed. In a few mills the spar before going to the chaser mills is crushed in a jaw crusher.

The material as it comes from the chasers is screened, the tailings being returned to the chaser mills for recrushing, while the fines go to tube mills for final grinding. The tube mills consist of steel cylinders revolving on a horizontal axis. The cylinders are generally lined either with hard-wood blocks or with blocks made of natural or artificial siliceous brick and are charged with Norway or French flint pebbles 2 to 3 inches across. The type of tube mill used by most feldspar grinders is 6 to 7 feet long and grinds from 2 to 3 tons of spar at one charging. Certain millers, however, claim to effect a considerable saving in power by the use of larger mills, which grind from 4 to 6 tons at one charge.

Feldspar for pottery purposes is usually ground four to six hours, and in that time most of it is reduced to a fineness of less than 200 mesh. Screen tests made by the writer on four samples of commercial ground pottery spar collected personally from the bins at three feldspar mills showed that from 99.3 to 99.8 per cent of the material would pass through a 100-mesh screen and from 96.7 to 98.2 per cent would pass through a 200-mesh screen. A sample of No. 3 spar, used only in making glass and enamel ware, was notably coarser, 94 per cent passing through a 100-mesh screen, and 74 per cent through a 200-mesh screen. This grade is ground only for two to three hours. Some feldspar prepared for use in abrasive soaps is ground for ten hours.

After grinding, the spar is ready for shipment either in bulk or in bags. The red spars from Bedford, N. Y., and Bedford, Ontario, have a faint pinkish tint when ground, but the cream-colored and white spars grind to a pure white. In a few mills the ground spar is allowed to settle slowly in water, so as to separate the finer from the coarser material, but this method is now rarely used.

In mills for grinding feldspar for poultry grit and roofing purposes the spar is first crushed in jaw or rotary crushers and then between steel rolls. It is then screened over vibrating screens, usually of the Newago or Jeffrey type, to the various sizes desired.

USES.

The principal consumers of feldspar are the pottery, enamel-ware, enamel-brick, and electrical-ware manufacturers, its most important use being as a constituent part of both body and glaze in true porcelain, white ware, and vitrified sanitary ware, and as a constituent of the slip (underglaze) and glaze in so-called "porcelain" sanitary wares and enameled brick. The proportion of feldspar in the body of vitrified wares usually falls between 10 and 35 per cent. Its melting point being lower than that of the other constituents, it serves as a flux to bind the particles of clay and quartz together. In glazes the percentage of feldspar usually lies between 30 and 50. The trade demands that feldspar for pottery purposes be nearly free from iron-bearing minerals (biotite, garnet, hornblende, tourmaline, etc.), and that it contain little if any muscovite. The requirements in regard to the percentage of free quartz vary with different potters. A few manufacturers of the finer grades of pottery demand less than 5 per cent of free quartz and may even grind the spar themselves so as to be sure of its quality, preferring to insure a constant product even at higher cost by themselves mixing the requisite quantity of quartz with the spar. Most potters get satisfactory results with standard ground spar carrying 15 to 20 per cent of free quartz, and in some acceptable spars the percentage runs even higher. In the finely ground mixture as it comes from the mills it is difficult to separate the quartz from the feldspar by physical methods on account of the extreme fineness of the material. Chemical analysis seems to be the readiest means of determining whether its percentage is high or low.

Feldspar is also used in the manufacture of emery and carborundum wheels as a flux to bind the abrading particles together.

Small quantities of feldspar are used in the manufacture of opalescent glass. The feldspar used for this purpose is ranked as No. 3 by the miners. This generally contains more free quartz and muscovite than that used for pottery purposes, and most of it contains also fragments of iron-bearing minerals. Most of the spars known to the writer which are used for opalescent glass are rich in soda. They are not ground so fine as the pottery spars (p. 128).

Small quantities of carefully selected pure feldspar are used in the manufacture of artificial teeth. Some is used in the manufacture of scouring soaps and window washes, the fact that feldspar is slightly softer than glass rendering these soaps less liable than soaps which contain quartz to scratch windows or glassware. Two firms in New York State and one in Connecticut crush feldspar for poultry grit and for the manufacture of ready roofing.

Much interest has recently been aroused in the use of potash feldspar as a fertilizer. Potash is an important plant food, which, in fertilizers, has usually been supplied in the form of wood ashes or imported from Germany in easily soluble potash salts (sulphate, carbonate, or chloride). The Department of Agriculture has recently made preliminary experiments to determine the availability of finely ground potash feldspar as a substitute for the more soluble potash salts. The following statement is quoted from the report on these tests:[a]

> The evidence so far obtained appears to indicate that under certain conditions and with certain crops feldspar can be made useful if it is ground sufficiently fine. On the other hand, it is highly probable that under other conditions the addition of ground feldspar to the land would be a useless waste of money. At the present stage of the investigation it would be extremely unwise for anyone to attempt to use ground rock, except on an experimental scale that would not entail great financial loss.

If further experiment shows that ground feldspar has a wide efficiency as a fertilizer, it will undoubtedly lead to the utilization of many of the pegmatite deposits which, because of insufficient coarseness, too large a percentage of quartz, or too great an abundance of iron-bearing minerals, are not valuable as a source of pottery material. Deposits of this kind, favorably situated with respect to the railroads, are numerous, especially in the vicinity of the active feldspar quarries. An equally important result will be the utilization of much material that is now discarded at feldspar quarries.

A number of processes have been patented in this country for the dissociation of potash feldspar to obtain the more readily soluble potash salts, but none of these have yet been successfully applied on a commercial scale. What is, perhaps, the most promising method effects the decomposition through electrolytic methods.[b]

GRADES AND PRICES.

Most dealers recognize three grades of commercial feldspar—No. 1, No. 2 (sometimes called standard), and No. 3. From quarries in granite pegmatite, where most of the spar is of the potash variety, these are usually graded as follows: No. 1 is carefully selected, free from iron-bearing minerals, largely free from muscovite, and contains little or no quartz, usually less than 5 per cent. Analysis 6 of the table, on page 123, shows the character of material of this grade, the feldspar analyzed having been imported from Canada. No. 2 is

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[a] Cushman, Allerton S., The use of feldspathic rocks as fertilizers: Bull. Bureau Plant Ind. No. 104 U. S. Dept. Agr., 1907, p. 31.

[b] Cushman, A. S., Extracting potash from feldspar: Min. World, June 22, 1907; also United States patent, No. 772612, October 18, 1904.

largely free from iron-bearing minerals and muscovite, but usually contains when ground from 15 to 20 per cent of quartz. No. 3 is not carefully selected and contains a little higher percentages of quartz, muscovite, and iron-bearing minerals. Spar from the soda pegmatites of southeastern Pennsylvania and adjacent parts of Maryland, being wholly free from quartz, is graded entirely on the basis of its freedom from iron-bearing minerals, principally hornblende. No. 1 is carefully selected and is practically free from such impurities. No. 2, though less carefully selected, is still fairly free from them. No. 3 is not carefully selected and carries hornblende in quantities large enough to render it unfit for use in the manufacture of pottery. It is utilized principally in making glass. Crushed pegmatite from New York State, used for poultry grit and for coverings for surfaces to give them the appearance of granite, and feldspar from Minnesota, used mainly for abrasive purposes, are graded according to coarseness.

The prices of feldspar fluctuate with general market conditions and local conditions of competition, but in general are about as follows:

Prices of feldspar f. o. b. mills.

	Crude, per long ton.	Ground, per short ton.
Maine: No. 2 or standard	$2.50-$3.00	
Northern New York: Crushed pegmatite for ready roofing, poultry grit, etc.		$3.00-$3.50
Southern New York:		
No. 1	4.24- 4.50	8.50- 9.00
No. 2, or standard	3.50- 4.00	6.00- 6.50
Connecticut: No. 2, or standard	3.50- 4.00	5.50- 6.50
Pennsylvania: No. 2, or standard (potash feldspar)	3.75- 4.50	7.50- 9.00
Maryland: No. 2, or standard (potash feldspar)	3.50- 4.00	
Trenton, N. J.:		
No. 1, Canadian	5.50	10.50
No. 2, or standard	5.00- 5.25	9.00- 9.50

Crude No. 1 feldspar usually brings from 50 cents to $1.50 a ton more than No. 2, and crude No. 3 brings about the same amount less. Ground No. 1 brings from $2 to $4 a ton more than No. 2. With finer grinding, such as is demanded by some scouring-soap manufacturers, the prices are proportionally higher. Very pure carefully selected potash feldspar, for use in the manufacture of artificial teeth, usually sells at from $6 to $8 a barrel of 350 pounds.

PRODUCTION.

The tables below show the recent production of feldspar in the United States.

Production of feldspar (exclusive of abrasive feldspar) in 1907 and 1908, by States, in short tons.

State.	Crude.		Ground.		Total.	
	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.
1907.						
Maine	45	$110	16,428	$157,224	16,473	$157,334
New York	3,909	15,825	11,500	40,500	15,409	56,325
Connecticut	10,663	28,433	8,380	51,770	19,043	80,203
Pennsylvania	7,367	28,169	12,266	108,678	19,633	136,847
Maryland	7,169	23,672	3,895	34,081	11,064	57,753
Other States	1,927	5,607	1,000	5,000	2,927	10,607
	31,080	101,816	53,469	397,253	84,549	499,069
1908.						
Maine	168	375	13,751	123,034	13,919	123,409
New York	504	1,350	14,109	51,798	14,613	53,148
Connecticut	7,775	27,753	6,425	38,506	14,200	66,259
Pennsylvania	3,616	13,226	10,473	90,276	14,089	103,502
Maryland	6,217	21,076	3,517	30,774	9,734	51,850
Virginia and Minnesota	560	2,000	125	750	685	2,750
	18,840	65,780	48,400	335,138	67,240	400,918

Total production of feldspar in 1907 and 1908, in short tons.

	Crude.		Ground.		Total.	
	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.
Production of feldspar (exclusive of abrasive) in 1908	18,840	$65,780	48,400	$335,138	67,240	$400,918
Production of abrasive feldspar in 1908	....	....	3,234	27,635	3,234	27,635
Total production of feldspar in 1908	18,840	65,780	51,634	362,773	70,474	428,553
Total production of feldspar in 1907	31,080	101,816	60,719	457,128	91,799	558,944

The production of feldspar (exclusive of abrasive feldspar) from 1903 to 1908 is given in the following table:

Production of feldspar (exclusive of abrasive feldspar), 1903–1908, in short tons.

Year.	Crude.		Ground.		Total.	
	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.
1903	13,432	$51,036	28,459	$205,697	41,891	$256,733
1904	19,413	66,714	25,775	199,612	45,188	266,326
1905	14,517	57,976	20,902	168,181	35,419	226,157
1906	39,976	132,643	32,680	268,888	72,656	401,531
1907	31,080	101,816	53,469	397,253	84,549	499,069
1908	18,840	65,780	48,400	335,138	67,240	400,918

QUARTZ.

GENERAL STATEMENT.

Quartz, the most abundant of all minerals, occurs in nature in a great variety of forms and is utilized commercially in many different ways. Sand consisting mainly of quartz is used for building, molding, and in glass and pottery manufacture. Tripoli, used for abrasive purposes, and sandstone and quartzite, used for building and other purposes, are also composed largely of quartz. The present discussion, however, deals only with the massive crystalline and gem varieties which occur in the pegmatite deposits.

Chemically pure quartz is an oxide of silicon of the formula SiO_2. It is too hard to be scratched with a knife and will itself scratch glass. It is generally translucent to transparent and ranges from colorless to dark gray, and in the gem varieties from amethyst to pale pink. It is brittle and without well-defined cleavage, fracturing irregularly with lustrous glassy surfaces. Most of the quartz of the pegmatites occurs in large pure masses without crystal outline. Quartz with crystal form is developed principally in the pockets. The form of most of the crystals is that of a six-sided prism terminated by an equal number of faces forming a pyramid. The mineral is difficultly fusible and is unaffected by acids under ordinary conditions.

MASSIVE CRYSTALLINE QUARTZ.

Occurrence.—Massive crystalline quartz is usually white, but some is rose-colored or smoky. It occurs in veins or dikelike masses, unmixed with other minerals, or as a constituent of pegmatite. In the latter form it is usually produced as an accessory in the mining of feldspar. The States producing massive crystalline (vein) quartz in commercial quantity in 1908 were Connecticut, Maryland, New York, Pennsylvania, Wisconsin, Tennessee, Montana, Colorado, and Arizona. Small quantities were formerly marketed from Maine, but these quarries are so far from the principal markets that there is very little profit in handling the material. Quartz of excellent grade occurs in considerable quantities at nearly all of the feldspar quarries of Maine and in a few is saved, though not shipped regularly. It is allowed to accumulate in stock piles until a favorable sale can be made.

The Connecticut localities at which quartz is mined were described in detail in the writer's report on the production of quartz and feldspar in 1907.[a] The quarries of Westchester County, N. Y., have also been previously described by the writer.[b]

Milling.—In the grinding of the massive forms of quartz two general processes are used, the wet and the dry.

[a] Mineral Resources U. S. for 1907, pt. 2, U. S. Geol. Survey, 1908, pp. 846-847.
[b] Bull. U. S. Geol. Survey No. 315, 1907, pp. 294-309.

In the wet process the quartz may be crushed just as it comes from the quarry, or it may first be highly heated in kilns and then fractured by turning upon it a stream of cold water. The first crushing is effected by jaw crushers, or if the quartz has previously been burned it may be crushed in chaser mills. In a few mills the chasers revolve in wet pans and are periodically stopped to allow the crushed quartz to be shoveled out. After crushing, it is ground in "wet pans" provided with a pavement of flat-faced quartz or quartzite blocks over which move several large blocks of similar material, the crushed quartz being pulverized between these blocks and the pavement. The grinding in wet pans usually occupies about twenty-four hours, the load ground in a single pan varying from 1,200 to 1,800 pounds. From the wet pans the pastelike mass of quartz and water is drawn into settling troughs, the first settlings being in some cases returned to the pans for finer grinding. From the settling troughs it is shoveled out upon drying floors heated by steam or hot air, or else it is dried in small pans which are placed tier on tier on heated racks constructed of steam pipes. Finally the dried material is bolted to various degrees of fineness and packed in bags for shipment, or it may be shipped in bulk.

In the dry method of treatment the quartz is usually crushed first in a jaw crusher and then between crushing rolls. Quartz to be used for filters and for abrasive purposes is then screened to various degrees of fineness and is packed in bags for shipment. In the manufacture of the finer grades for use in pottery, wood fillers, scouring soaps, etc., the material after leaving the roll crushers is ground in tube mills, either of the continuous or of the intermittent type. It is then graded to various sizes either by bolting or by a pneumatic process whereby the quartz powder is carried by a strong air current through a series of tubes and receptacles, the distance to which the quartz is carried being dependent upon its fineness. There are no quartz mills in Maine. Those nearest to that State are in Connecticut.

Uses.—Quartz is used for a great variety of purposes, the principal uses being in the manufacture of wood filler, pottery, paints, and scouring soaps. In pottery the quartz serves to diminish shrinkage in the body of the ware; it is used also in many glazes. Quartz for these purposes should contain in general less than one-half of 1 per cent of iron oxide. Finely ground quartz is used in paints in various proportions up to one-third of the total pigment used. Its chemical inertness prevents it from combining with other constituents of the paint and increases the resistance of the paint to the weather. Crystalline quartz is superior to silica sand for this purpose because the ground particles are highly angular and tend to attach themselves more firmly to the painted surfaces, thus giving the paint what is known as a "tooth" and after some wear affording a good surface for repainting. This angularity of the grains also renders the ground crystalline quartz superior to silica sand in the manufacture of wood fillers. In scouring soaps and polishers ground crystalline quartz is preferred to silica sand, not only because of its greater angularity, but because of its superior whiteness.

Massive quartz, crushed and graded to various degrees of fineness, is extensively used in sandpaper, sand belts, scouring agents, sand blasts, etc. The qualities which render it particularly serviceable for these purposes are its hardness (No. 7 in the Mohs scale), which is slightly greater than that of steel, and its conchoidal fracture, the absence of definite cleavage planes causing it to crush to fragments with sharp angular edges and corners. For such abrasive purposes massive quartz is far superior to sand or crushed sandstone, since the grains of the latter are likely to be more or less rounded. Blocks of massive quartz and quartzite are used in the chemical industry as a filler for acid towers and to some extent as a flux in copper smelting. Much ground quartz is used in filters, and some of the most finely pulverized grades are used in tooth powders and in place of pumice as a cleaner by dentists.

Within recent years crystalline quartz and also sand has been used to some extent in the manufacture of silicon and of alloys of silicon with iron (ferrosilicon), copper (silicon copper), and other metals. Ferrosilicon is largely produced in the electric furnace by using coke to reduce the quartz to the metallic state, and some iron ore or scrap iron to alloy with the silicon. The percentage of silicon in these alloys varies from about 10 to 80 per cent, according to the uses of the product. Ferrosilicon has been employed in the manufacture of steel as a deoxidizer and to prevent the formation of blowholes in steel ingots. Silicon is also produced in the electric furnace.[a] It is a brittle crystalline body with a dark silver luster. Its specific gravity is about 2.4 and its melting point 1,430° C. The commercial product contains small percentages of iron, carbon, and aluminum. The great affinity of silicon for oxygen renders it useful for the reduction of metals such as chromium and tungsten in the electric furnace. It can readily be cast into rods, and because of its high electrical resistance, which is about five times that of carbon, it is used in the manufacture of rheostats and electrical heaters. Its resistance to nearly all acids, combined with the fact that it can be cast into molds, makes it possible also to use it in the manufacture of chemical ware. Silicon copper is used as a deoxidizer in making castings of copper and copper alloys.

Quartz may be fused in the electric furnace and molded into tubes, crucibles, dishes, and other articles which can be used for certain

[a] Tone, F. J., Production of silicon in the electric furnace: Trans. Am. Electro-Chem. Soc., vol. 7, 1905, p. 243.

purposes in the chemical laboratory instead of porcelain and platinum wares. The fused quartz expands only very slightly when heated, its coefficient of expansion being about one-twentieth of that of glass, and in consequence may be plunged suddenly, red hot, into cold water without being cracked. These wares soften only above 1,400° C. (2,552° F.). The principal drawback to their use, especially in quantitative chemical work, is that the somewhat rough surface makes it difficult to wash all the material from the dishes.

Production.—Statistics showing the production of quartz in the United States are given below.

Production of quartz (exclusive of abrasive quartz) in the United States in 1908, by States, in short tons.

State.	Crude.		Ground.		Total.	
	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.
1908.						
Connecticut and New York	980	1,750	9,227	56,700	10,207	58,450
Pennsylvania and Maryland	25	99	4,160	31,670	4,185	31,769
Other States [a]	22,500	30,594	1,933	17,833	24,433	48,427
	23,505	32,443	15,320	106,203	38,825	138,646

[a] Includes Arizona, Colorado, Montana, Tennessee, and Wisconsin.

Abrasive quartz was produced in 1908 in Connecticut, Maryland, Massachusetts, New York, Pennsylvania, and Wisconsin. The total, together with the total production of all quartz, is shown in the following table:

Total production of quartz in 1908, in short tons.

	Crude.		Ground.		Total.	
	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.
Quartz (exclusive of abrasive quartz)	23,505	$32,443	15,320	$106,203	38,825	$138,646
Abrasive quartz	2,973	4,876	5,518	46,635	8,491	51,511
	26,478	37,319	20,838	152,838	47,316	190,157

Production of quartz (exclusive of abrasive quartz) in the United States, 1903–1908, in short tons.

Year.	Crude.		Ground.		Total.	
	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.
1903	40,046	$38,736	15,187	$118,211	55,233	$156,947
1904	41,490	28,890	10,780	71,700	52,270	100,590
1905	39,555	33,409	11,590	70,700	51,145	104,109
1906	41,314	37,632	25,383	205,380	66,697	243,012
1907	5,618	4,282	17,359	152,812	22,977	157,094
1908	23,505	32,443	15,320	106,203	38,825	138,646

Prices.—Pure crystalline quartz for use in the manufacture of pottery, abrasive soaps, paints, wood fillers, etc., brings usually from about $2 to $3.50 per long ton, crude, f. o. b. quarries, and the ground material brings from $6.50 to $10 per short ton f. o. b. mills, the price varying with fineness of grinding, distance from markets, etc. The purer varieties of quartzite used for similar purposes and for sand-papers sell, as a rule, at somewhat lower prices, the crude bringing from about $1 to $2 per long ton f. o. b. mines, and the ground from $6 to $8 per short ton f. o. b. mills. The finest grades of crystalline quartz ground to an impalpable powder and used for tooth powders, etc., may bring as high as $20 per ton f. o. b. mills. Imported French flints cost from $3.50 to $4 per long ton f. o. b. Philadelphia, and can be delivered in Trenton, N. J., for less than $5 per long ton.

SMOKY QUARTZ.

Smoky quartz has somewhat the appearance of smoked glass, though varying from a faint tint of gray or yellowish brown to nearly black. The shade commonly varies considerably from point to point in the same crystal.

Transparent crystals have been found in a number of the pegmatite masses of Maine and some are of value as museum specimens and as gems. In 1884 a mass weighing over 6 pounds, with clear spaces several inches across, was found on Blueberry Hill in the town of Stoneham, Oxford County, and a broken crystal that weighed over 100 pounds and another 4 inches long and 2 inches across, very clear in parts, were found near Mount Pleasant in Oxford County. On the southwestern slopes of Mount Apatite in Auburn, Androscoggin County, a large pocket in coarse pegmatite has yielded considerable quantities of fine crystals. Transparent quartz of pale amber-brown color has been observed by the writer at the Berry quarry, a short distance south of Mount Apatite in Poland, one mass showing a clear portion 3 by 5 inches in size.

The nature of the coloring matter is not known, but on heating the smoky varieties generally become first yellow and finally colorless. Some yellow quartz produced in this way is cut as a gem under the name of "Spanish topaz" or "citrine," though the true citrine is a natural occurrence of transparent yellow quartz. Crystals or irregular masses of transparent smoky quartz found in any of the feldspar or gem quarries should be preserved, for they may prove of value and interest to the mineral or gem collector.

ROSE QUARTZ.

Most of the rose quartz found in Maine is somewhat paler in tint than that commonly utilized as a gem stone, though occasionally some of deeper tint is obtained. The principal supplies of this material at present come from South Dakota and Colorado. In Maine it forms irregular masses in the pegmatite and usually grades into white quartz; it has not been found in distinct crystals. It occurs in a number of the smaller pegmatite bodies of Oxford County, notably at Tubbs Ledge in Norway, Frenchs Mountain in Albany, and occasionally at Mount Mica in Paris, but so far as known very little has been marketed. In a few places the pale-rose varieties show a milky opalescence and are very beautiful when well polished.

Rose quartz from the Red Rose mine in South Dakota is reported to have sold in 1908 at from 3 to 25 cents per pound, according to depth of color and number of flaws or seams. Selected material brought from $8 to $12 per pound.

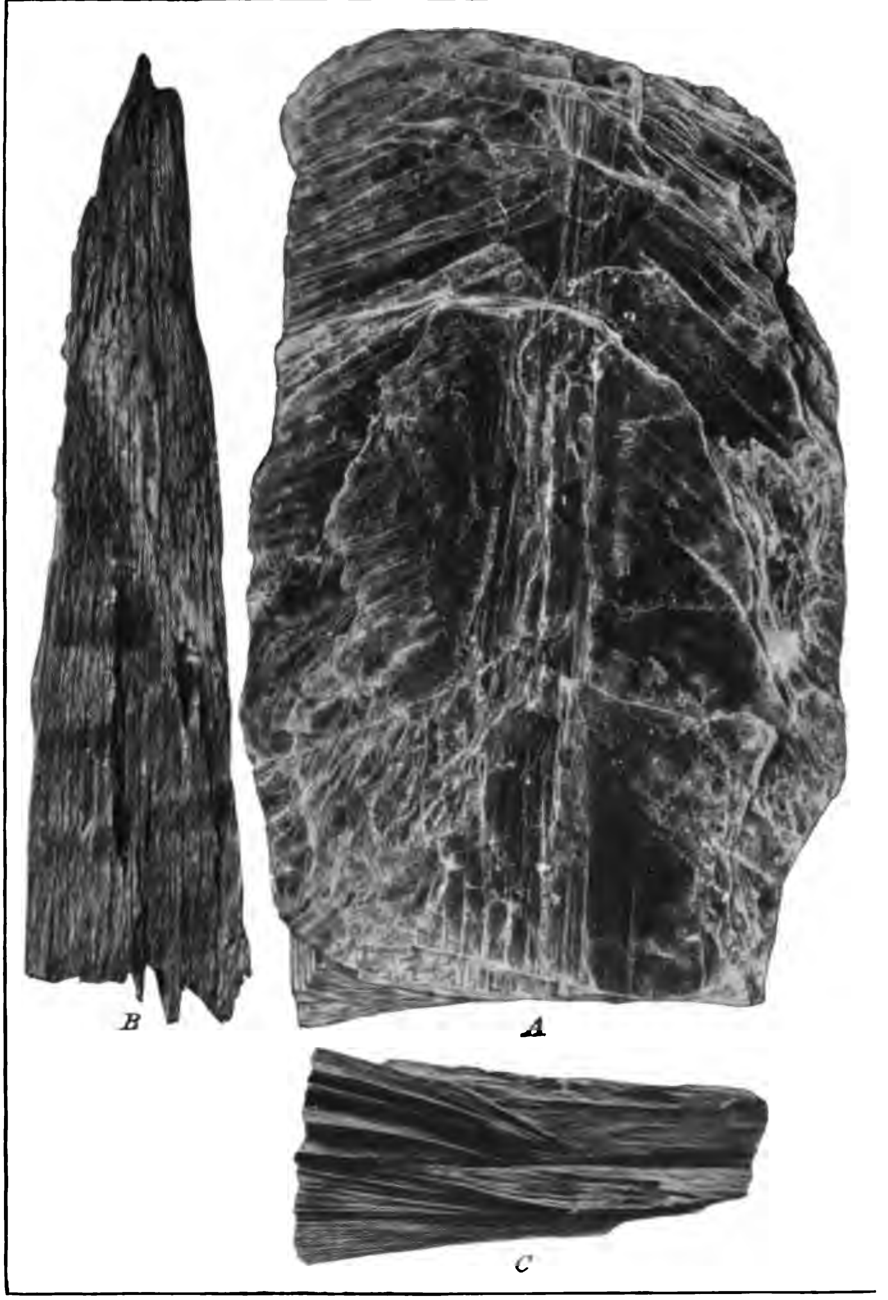
AMETHYST.

Amethystine quartz, or amethyst as it is commonly called, is a transparent purple or violet variety of quartz and is one of the semiprecious stones. It must not be confused with the oriental amethyst, which is a rare purple variety of corundum and is much more precious. Deer Hill in the extreme northwestern part of the town of Stow, Oxford County, has furnished large numbers of amethyst crystals, but nearly all of them are of a pale tint and of little value as gems. They occur in pockets in the coarse pegmatite and also in the soil on the southeast slope of the hill, where the pegmatite is associated in a most irregular manner with fine-grained granite. Recently George Howe, of Norway, Maine, has found some remarkably fine specimens of amethyst on Pleasant Mountain, in the town of Denmark, Oxford County. By transmitted daylight these stones are a deep royal purple, but by lamplight they are a rich wine red.

As in the case of most other Maine gems, the retail prices obtained within the State for Maine amethysts are considerably higher than those prevailing in the New York market. They range up to $10 a carat for well-cut stones of the paler varieties, and from $10 to $18 a carat for those showing the deep colors.

MICA.

Types.—Mica is a group name comprising a number of mineral species, the most important of which, economically, are biotite (brown mica), muscovite (white mica), phlogopite (amber mica), and lepidolite (pink or lilac mica). Though biotite is occasionally ground for commercial purposes, it is so intimately intergrown with other constituents in the Maine pegmatites as to be unavailable even for such treatment. Lepidolite from Mount Mica, usually intergrown with some albite feldspar, has been cut into slabs and polished for paper weights, and has also been used to some extent as a source of lithium



MUSCOVITE FROM TOPSHAM, SHOWING WEDGE STRUCTURE.

A, Front view. *B*, Side view. *C*, End view. Natural size.

salts; its use, however, is sporadic and it commands no steady market price. Phlogopite, which is produced in large quantities in Canada and is used for the same purpose as muscovite, is not found in commercial amounts in the United States. Muscovite is the only mica variety of commercial importance produced in Maine.

Physical and chemical properties.—Muscovite is a hydrous silicate of alumina and potash with a little water and usually a little iron. The hardness of the mineral is between 2 and 3; that is, mica is generally soft enough to be scratched with the finger nail. It is practically infusible at ordinary temperatures. The color is usually a silver gray or light yellow, and the mineral is generally transparent. It is attacked with difficulty by reagents and in nature successfully resists decomposition for long periods. Few minerals are so widely distributed. In small flakes it is a common constituent of a great variety of rocks, but in large crystals, such as can be used commercially, it is generally confined in Maine, as elsewhere, to pegmatite deposits. Its most striking physical characteristic is its highly perfect basal cleavage, which causes it to split into tough, flexible sheets whose thickness may be less than a thousandth of an inch. The crystals as they occur in the pegmatite thus resemble, in a rough way, thick pads of paper or books. The name "books" is, indeed, frequently used in the trade as a convenient descriptive term for the mica crystals. A few of the books show regular hexagonal borders, but as a rule their outlines are irregular.

Muscovite may exhibit certain characteristics not mentioned above, which may seriously affect its commercial value. These may be enumerated as follows:

By far the commonest defect noted in the muscovite of the Maine pegmatites is what is usually termed A structure. This appears to be due to a wedging out of the mica folia in two directions inclined to each other at 60°. It is recognized in a mica book by the presence of two sets of striations at 60° to each other and parallel to the directions of the "ruling." In most of the Maine quarries such A structure is repeated by twinning with the production of what is commonly termed "fish-bone" or "herring-bone" structure (Pl. XIX). Muscovite showing A and fish-bone structure is generally used only as scrap mica. The material obtained at the Black Mountain mine in Rumford was wholly of this type, and material showing these characters is found in nearly all the pegmatite deposits which have been worked commercially either for feldspar, mica, or gems, and even in deposits where good plate mica is also found.

A second defect frequently met is commonly termed "ruling" and consists in the presence of sharp, straight fractures parallel to the sides of the crystal and thus highly inclined to the plates. These are in fact the secondary or less perfect cleavage directions and they commonly divide a mica mass into a number of long narrow ribbon-shaped strips. Many large clear books which otherwise could be cut into large pieces of mica are, because of this ruling, rendered no more valuable than much smaller books which are free from this defect. In some crystals instead of actual cleavage there is a folding or wrinkling of the mica laminæ parallel to the secondary cleavage directions, which suggests that both wrinkling and actual cleavage may be developed in some cases as the result of strains to which the mica books have been subjected. In specimens from the Hibbs mine in Hebron the secondary cleavage has produced a multitude of fractures so close together that their intersection with the principal cleavage planes reduces the mica to a mass of fine fibers.

Plate mica which might otherwise be of good quality is sometimes injured by the presence between the laminæ of thin crystals of magnetite and other minerals usually showing more or less regular radiating or dendritic forms. Some of the crystals of magnetite occurring in this way are so extremely thin that they are transparent. The presence of these magnetite crystals injures the mica for electrical insulating purposes, as they form a path for the current and may lead to a puncturing of the plate and short-circuiting. Some such mica is, nevertheless, used to some extent in the electrical industries.

Perfectly colorless mica bears the highest value, though a slight tinge of color is for most purposes not regarded as a defect.

Occurrence.—In some places, as at the Waterford quarries and Black Mountain mica mine in Rumford, Oxford County, the muscovite is more or less evenly distributed throughout the coarser portion of the pegmatite mass. At Black Mountain it is all of the wedge variety, some of the spatulate mica books being 3 feet in length and 1½ feet in maximum width. In most localities, however, though present to some extent in all parts of the pegmatite mass, muscovite is much more abundant along certain zones. The commonest mode of occurrence is illustrated in Plate IX, *A*, and has been described on page 26. More or less rounded aggregates of small muscovite plates occurring in certain feldspar quarries have also been described (p. 115). At the Hibbs mica and feldspar mine in Hebron, muscovite, mostly of the wedge variety, occurs sparingly throughout the whole pegmatite mass, but the plate mica is almost wholly confined to a zone 3 to 4 feet in width along the southwest wall of the pegmatite body. It makes up about 10 per cent of this zone, the other minerals being feldspar and quartz. The books are variously oriented; some of them have a width of 30 inches, though the average is about 5 inches.

Mica is not now being mined in Maine and the efforts to mine it in the past have for the most part proved unprofitable because of the small amount or poor quality of the material obtainable as compared with other mica-producing districts. It seems probable that a few of the Maine deposits could be worked in a small way with profit, but the industry can never be of much magnitude unless there is a marked increase in the demand for scrap mica. Localities where it has been mined are Albany, Hebron, Peru, Black Mountain in Rumford, and Waterford, all in Oxford County. The mines are described in the locality descriptions. Deposits of mica have been found in about twenty States of the United States, and have been worked profitably in a number of them. Among the States where mica has been actively mined are North Carolina, South Dakota, New Hampshire, Colorado, Virginia, Alabama, South Carolina, Idaho, and New Mexico.

Mining and manufacture.—The mica mining at the Hibbs mine in Hebron is accessory to the mining of feldspar, both minerals being loosened by hand drilling, succeeded by blasting. At the Black Mountain mine in Rumford the material, which was all scrap mica, was loosened by steam drilling and blasting and was then picked over so as to free it entirely from fragments of quartz or feldspar or other minerals. It was then placed in 100-pound bags, hauled to the railroad, and shipped to Gildersleeve, Conn., for grinding.

At the Beach Hill mine in Waterford the mica, after being thoroughly cleaned of adhering matter, was split up with a stout knife into plates averaging about one-sixteenth of an inch in thickness. If these plates showed fractures or creases they were then cut into two or more pieces, the knife following the cracks or creases so as to eliminate the imperfections and at the same time leave as large perfect plates as possible; this process is known as thumb trimming. Most of the plate mica was marketed in this form, though some of the output was further trimmed to various standard market sizes.

Uses.—The following account of the uses of mica is quoted from a report by Douglas B. Sterrett:[a]

The principal use for mica during recent years has been and still is in the manufacture of electrical apparatus; formerly its application in stove manufacture consumed the bulk of the production. The glazing industry still consumes much of the finest grades of sheet mica in the manufacture of windows for coal, gas, and oil stoves, gas-lamp chimneys, and in many minor uses, as lamp shades, fronts for fancy boxes, etc. The use of mica as an insulating material in electrical apparatus and machinery is extensive. Many forms of dynamos, motors, induction apparatus using high voltage, switchboards, lamp sockets, etc., have sheet mica in their construction. For practically every purpose of electrical insulation, with the exception of commutators of dynamos and motors, the domestic mica is as satisfactory as any other. For insulation between the copper bars of commutator segments, however, no mica produced in the United States is as satisfactory as the "amber" or phlogopite mined in Canada and Ceylon. This is due to the fact that the "amber" mica wears down evenly with the copper segments, while the ordinary white or muscovite mica, through its greater hardness, does not wear down so rapidly and is left in ridges above the copper, causing the

[a] Mineral Resources U. S. for 1908, pt. 2, U. S. Geol. Survey, 1909, p. 751.

motor to spark. Much of the sheet mica used in electrical apparatus is first made up into large sheets of mica board or micanite. In this form it is available for use in most of the purposes for which ordinary sheet mica can be used. It can be bent, rolled, cut, punched, etc. Bending is accomplished during baking, or by heating to soften the shellac used in the manufacture of the mica board. Insulation for commutators is generally cut from "amber" mica board.

Scrap mica, or mica too small to cut into sheets, and the waste from the manufacture of sheet mica are used in large quantities commercially. The greater part is ground for the manufacture of wall papers, lubricants, fancy paints, molded mica for electrical insulation, etc. Ground mica applied to wall papers gives them a silvery luster. When mixed with grease or oils mica forms an excellent lubricant for axles and bearings. Mixed with shellac or special compositions, ground mica can be molded into desired forms, and is used in insulators for wires carrying high potential currents. Ground mica for use in molded mica for insulation purposes should be free of metallic minerals. For lubrication purposes it is necessary that gritty matter be eliminated, either after grinding or by using only pure mica for grinding. For wall papers and brocade paints a ground mica with a high luster is required. This is best obtained by using a clean light-colored mica and grinding under water.

Coarsely ground or bran mica is used to coat the surface of composition roofing material, especially that manufactured by the Western Elaterite Roofing Company, of Denver, Colo. The mica serves the purpose of keeping the material from sticking when rolled for shipping or storage.

In the Western States the dry process is the common practice in grinding mica, but in the mica regions of the Eastern States the greater part of the mica is ground under water. In dry-grinding machines the mica is pulverized by the beating action of teeth or bars on cylinders revolving at a high rate of speed. In wet-grinding machines the mica is beaten and torn under water by teeth or spikes mounted in wheels or cylinders revolving at a comparatively slow rate of speed. The capacity of the dry-grinding machines or pulverizers is considerably greater than that of the wet-grinding machines. The dust of fine mica scales from the pulverizers is often a cause of annoyance to workmen around the mills, as it is very irritating to the throat and lungs when breathed. It is claimed that mica ground under water is better than that ground dry. Some consumers demand the wet-ground mica, claiming a greater purity and more brilliant luster. It is possible that the same effect could be obtained by thoroughly washing dry-ground mica and floating the product.

PRICES AND PRODUCTION.

The following statements in regard to the price of mica are also quoted from Sterrett's report:

The average price of sheet mica in the United States during 1908, as deduced from the total production, was 24.1 cents per pound, as compared with 33 cents per pound in 1907 and with 17.7 cents in 1906. The average prices per pound of sheet mica as reported in the production from several States were as follows: Virginia, 44.2 cents; South Carolina, 35.7 cents; South Dakota, 33.3 cents; Alabama, 24 cents; North Carolina, 19.1 cents. These average values vary greatly from year to year, a result caused in part by variation between the proportion of rough and trimmed sheet mica sold by the producers and in part by variation in the size of sheet produced.

The prices of several sizes of selected mica quoted in the price list of a large mica company of New York during 1908 were as follows:

Prices per pound of selected sizes of sheet mica at New York in 1908.

2 by 2 inches	$0.87	3 by 4 inches	$3.25
2 by 3 inches	1.10	4 by 6 inches	4.75
2 by 5 inches	1.70	6 by 8 inches	6.75
3 by 3 inches	2.75		

In most years the importations of mica into the United States are largely in excess of the domestic production in value. They come mainly from India and Canada.

TOURMALINE.

Chemical and physical properties.—Tourmaline is a complex silicate of boron and aluminum containing various amounts of either magnesium, iron, or the alkali metals. The form of the more perfect crystals is commonly that of a three-sided prism, the sides of the prism usually being striated and channeled (Pl. XV). In many crystals the three-sided form is somewhat modified by the combination with it of a hexagonal prism. The latter is usually subordinate and has the effect of merely somewhat rounding the angles of the triangular prism. Many crystals are terminated by three planes forming a low pyramid, but in others the number of terminal planes is very large. The hardness (7 to 7.5) is slightly greater than that of quartz. There is no well-defined cleavage.

The mineral exhibits a great variety of colors, ranging from black through brownish-black and blue-black to blue, green, red, pink, and colorless. The red varieties go under the name of rubellite; the blue varieties are known as indicolite and the colorless as achroite. A crystal may be green at one end and red at the other or in cross section may show a blue center, then a zone of red, and then one of green. Some of the crystals from Paris, Oxford County, grade from white at one termination to emerald green, then light green, then pink, and finally are colorless at the other termination. The color is dependent on the chemical composition, the green, blue, pink, and colorless varieties generally being rich in lithium and manganese and the dark opaque varieties being particularly rich in iron. The color in the transparent varieties varies with the direction in which the light penetrates the gem; thus a crystal which, when viewed from the side, is a transparent green, may be opaque or yellow-green when viewed along the length of the prism. Because of this property of dichroism, as it is called, it is usually necessary in cutting gem tourmalines to make the "table" of the stone parallel to the long axis of the crystal. Another distinctive quality of the mineral is that it becomes electrified when warmed slightly and is then capable of picking up ashes, small scraps of paper, etc.

Occurrence.—Tourmaline occurs in small crystals in a great variety of rocks and may be either an original crystallization or the result of metamorphic processes. Large crystals and those which are of gem value occur only in the pegmatite deposits. The black varieties occur almost exclusively in the solid pegmatite associated with quartz and feldspar and without any regularity in arrangement. The black varieties may contain from 3 to nearly 20 per cent of oxides of iron and must be carefully separated from feldspar which is to be used for pottery purposes. The colored varieties occasionally are found also in the solid pegmatite, as at the Newry mine (p. 76), but where occurring in this way seldom yield much gem material because of the difficulty of removing them unfractured from their matrix. The colored tourmalines showing the greatest perfection in crystal form and yielding most of the gem stock occur in pockets in the coarse pegmatite bodies. For a detailed description of their mode of occurrence the reader is referred to the description of Mount Mica (pp. 81–93).

Outside of Maine gem tourmalines are produced in the United States in important amounts only in Connecticut and California. Abroad they are found in Brazil, in the Ural Mountains, and in Ceylon.

Mining, prices, etc.—Mount Mica in Paris and Mount Apatite in Auburn are the only localities where systematic mining for tourmalines is now being carried on, although a few gem tourmalines are occasionally found at certain of the feldspar quarries. The quarries have been described in the detailed locality descriptions. In general, the excavation must proceed with great caution; the drilling must be done in a most careful manner, much of it by hand; and heavy charges of explosives must be avoided because of the liability of shattering valuable gem material.

Most of the gem tourmalines now mined in Maine, when not preserved for museum purposes, are cut within the State by lapidaries whose workmanship is said often to equal that of the best New York cutters. The size and general character of the finest gems which have been cut is described in the discussion of Mount Mica. The great bulk of the cut tourmalines marketed are, however, below 3 carats in size. Rubellites and stones of a color approaching an emerald green are the most valuable.

The prices obtained in Maine are higher than those current in New York City, because most are sold at retail to residents of the State or to summer tourists and have an enhanced value as souvenirs. Rubellites and emerald-green varieties bring at retail from $8 to $20 per carat. The indicolite and olive-green varieties bring from $6 to $18 a carat.

BERYL.

CHEMICAL AND PHYSICAL PROPERTIES.

Under the name beryl are included the opaque beryl found in nearly all the pegmatite dikes and the much rarer gem varieties, emerald, aquamarine, golden beryl, and cæsium beryl. In chemical composition beryl is a silicate of beryllium and alumina having the general formula of $Be_3Al_2Si_6O_{18}$ or $3BeO.Al_2O_3.6SiO_2$, but with the beryllium oxide replaced in some varieties by soda, lithia, or calcium oxide. The mineral has a hardness of 7½ to 8; that is, it can not be scratched with a knife. The color varies from emerald green through pale green, light blue, and golden yellow to white and pale pink. The crystals are generally hexagonal prisms, many of them striated vertically, and most of them terminated by a single flat plane at right angles to the long axis of the prism. Some pyramidal terminations also occur. There is no marked cleavage, only an imperfect one parallel to the basal planes. Beryl is fusible only with difficulty and is not attacked by acids.

OPAQUE BERYL.

The commoner varieties of beryl are light blue or green in color, and are opaque, though portions of some crystals are transparent and may even yield gems. Opaque crystals are quite common in most of the coarser pegmatite deposits of Maine, where they occur as more or less regular prisms embedded in the solid pegmatite. Some of these reach remarkable dimensions; one found in the Maine Feldspar Company's quarry at Mount Apatite in Auburn was described as having a diameter equal to that of a hogshead. One from the Noyes gem mine in Greenwood, Oxford County, was so large that a man could barely reach around it with his arms. From Acworth, N. H., one crystal 6½ feet long and another estimated to weigh over 2½ tons were quarried. A peculiar beryl from Auburn is described by Kunz as follows:[a]

> In the state cabinet in Albany, N. Y., is a curious beryl found by S. C. Hatch at Auburn, Maine. It is of imperfect structure and broken diagonally across, showing the structure to advantage. It is 8¾ inches (30 centimeters) high, 8¾ inches (22 centimeters) wide, and has 50 different layers, 25 of beryl, the remaining 25 of albite, quartz, and muscovite. All the corners of the hexagonal prism are carried out in full, giving the beryl an asteriated appearance and making it a striking and interesting specimen.

The opaque varities of beryl are of little commercial value, though prized for museum collections when they show perfect crystal forms.

EMERALD.

Transparent beryl of deep-green color is the gem emerald, but it must not be confused with the oriental emerald, which is a green variety of corundum. Emeralds are of rare occurrence in the pegmatite deposits of Maine. One crystal of light grass-green color embedded in quartz was observed by the writer at the Dunton gem quarry in Newry, Oxford County. It was a prism half an inch across and 1½ inches long but was so badly fractured as to be valueless for gems. Parker Cleveland[b] mentions having seen several emeralds from Topsham, Sagadahoc County, of a lively green color and

[a] Kunz, G. F., Gems and precious stones, pp. 91-92.
[b] Mineralogy and geology, 1822.

comparable in beauty to the Peruvian emeralds, but none are now in the museums and none, so far as the writer knows, have since been found. In the United States emeralds are found in important quantities only in North Carolina. Abroad they are obtained in Colombia, the Urals, Austria, and upper Egypt.

AQUAMARINE.

The light-blue to sky-blue and light-green transparent varieties of beryl known as aquamarine are more abundant than any of the other gem varieties of beryl found in Maine, and specimens of remarkable size and beauty have been obtained. The prismatic crystals lie in various positions in the solid pegmatite masses and are more commonly associated with quartz than with the other constituents. Few of them occur in pockets. Their position in the solid ledge renders it difficult to obtain the crystals without more or less fracturing. Some few crystals come from quarries which are worked primarily for feldspar or for tourmalines, but the principal supply, like that of golden beryl, is obtained by gem collectors who work small prospects, using hand drills and light blasts of powder.

Most of the gem material has come from Oxford County. Some has been obtained from what is known as the Emmons mine in the southwestern part of Greenwood, from Frenchs Mountain in Albany, Sugar Hill in Stoneham, and Lovell, Bethel, and other towns. A fine sea-green aquamarine weighing about 7 carats was found near Sumner. Recently some good gems have been obtained on the Dudley farm in Buckfield.

The price obtained at retail for the cut stones ranges from $4 to $15 per carat for perfect stones, depending on the size and color. Most of the stones now obtained in Maine are cut and marketed within the State.

GOLDEN BERYL.

Beautiful transparent golden-yellow beryls have been obtained in the pegmatites at various points in Oxford County, at Edgecomb Mountain in Stoneham, in Albany, and recently good gem material of a straw yellow has been obtained from the west side of Speckled Mountain in Peru. They are mined sporadically by gem collectors, mostly from small prospects. The retail prices obtained for flawless cut stones of this variety vary from $10 to $25 per carat, depending upon the size and color. Nearly all that are found are sold to residents or to visitors, and as native Maine gems command a higher price than they would in the general markets.

CÆSIUM BERYL.

A colorless to bluish-white or pinkish-white variety of beryl containing a small percentage (1.66 per cent to 3.6 per cent) of oxide of cæsium was first discovered in Hebron, Oxford County, but has since been found to occur at a number of other pegmatite localities in the western part of the State, notably at Mount Mica in Paris, at the Dudley farm in Buckfield, Oxford County, and at the feldspar quarry of Mr. A. R. Berry in Poland, Androscoggin County. Generally it occurs in somewhat irregular masses in the solid pegmatite, but in some occurrences shows regular crystal forms. When cut it makes a stone of high brilliancy which as a night stone is considered by some to be superior to many diamonds. It is valued chiefly because of its resemblance to the diamond. Flawless cut stones of moderate sizes sell at retail at present at from $5 to $20 a carat.

TOPAZ.

Topaz is a silicate of alumina containing fluorine and having about the composition $Al_{12}Si_6O_{25}F_{10}$. It may be colorless, straw yellow, or wine yellow, or may show faint tints of gray, green, blue, or red. Its hardness is 8, and it is thus capable of scratching quartz. It is also much heavier than quartz, having a specific gravity of 3.4 to 3.65. The mineral belongs to the orthorhombic system and its crystals are usually prismatic in form, with one end terminated by crystal faces. It possesses a perfect cleavage at right angles to the prism axis. Transparent smoky quartz is frequently called smoky topaz, and the so-called Spanish topaz is simply smoky quartz heated until it assumes a yellow color. Clear, colorless quartz is also sometimes sold under the name of topaz.

So far as known to the writer, topaz in any considerable amounts has been found in Maine only at Harndon Hill in Stoneham, Oxford County. (See p. 100.)

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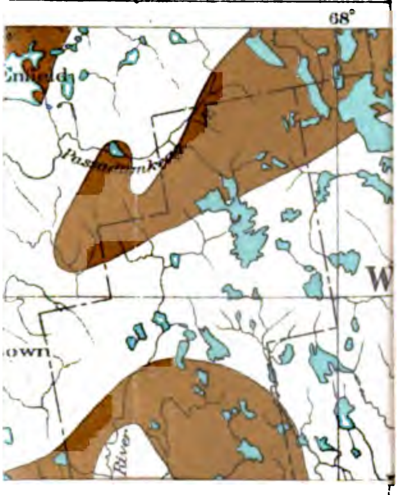
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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

BULLETIN 446

GEOLOGY

OF THE

BERNERS BAY REGION

ALASKA

BY

ADOLPH KNOPF

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ILLUSTRATIONS.

PREFACE.

By Alfred H. Brooks.

The general plan for the Alaskan work provides first for reconnaissance surveys which it is intended eventually to extend over the entire Territory. These reconnaissance surveys are followed by the detailed mapping of the most important mining district.

The first investigation of the mineral resources of southeastern Alaska by the Geological Survey was made by Becker[a] in 1895. More systematic surveys of Alaska were begun in 1898, but for several years the demands of the unexplored regions of the interior prevented any attention being given to the coastal provinces. In 1901 a hasty examination of the Ketchikan district[b] was undertaken, and in 1903 and 1904 reconnaissance surveys of the Juneau and Porcupine districts[c] were completed. Reconnaissance surveys have been continued in southeastern Alaska up to the present time. With the publication of the report on the Wrangell and Ketchikan districts[d] in 1908 all the most important mining regions were covered. There still remain, however, extensive areas in southeastern Alaska of which the geology is but little known.

Meanwhile some detailed geologic studies have been made. In 1902 and 1903 the detailed geologic[e] and topographic[f] mapping of the most productive part of the Juneau district was completed. Between 1906 and 1908 detailed topographic surveys of the Kasaan Peninsula, Karta Bay, and Hetta Inlet copper-bearing areas were completed. Owing to circumstances beyond the control of the writer, the results of these surveys have not been published, but it is hoped that they may be issued during 1911. Plans for detailed studies of the Berners Bay region were formulated in 1906, when a topographic survey of the district[g] was made. Owing to the litigation in which several of

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[a] Becker, G. F., Reconnaissance of the gold fields of southern Alaska, with some notes on the general geology: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1897, pp. 1-86.

[b] Brooks, A. H., Preliminary report on the Ketchikan mining district, with an introductory sketch of the geology of southeastern Alaska: Prof. Paper U. S. Geol. Survey No. 1, 1902.

[c] Spencer, A. C., The Juneau gold belt; Wright, C. W., A reconnaissance of Admiralty Island: Bull. U. S. Geol. Survey No. 287, 1906. Wright, C. W., The Porcupine placer district: Bull. U. S. Geol. Survey No. 236, 1905.

[d] Wright, C. W. and F. E., The Ketchikan and Wrangell mining districts, Alaska: Bull. U. S. Geol. Survey No. 347, 1908.

[e] Spencer, A. C., Bull. U. S. Geol. Survey No. 287, 1906.

[f] Juneau special map, U. S. Geol. Survey, 1904.

[g] Berners Bay special map, No. 581B, U. S. Geol. Survey, 1908.

the largest mining properties of the district have been involved, the geologic work was postponed until last year (1909), when the settlement of one of the important lawsuits gave promise that the district would soon become an important gold producer.

The heavy growth of timber, the thick underbrush, and the mat of moss mantle the bed rock of much of this region to such an extent as to make detailed geologic surveys almost hopeless. It is for this reason that but few cartographic units have been used in representing the geology. It is believed, however, that the subdivisions made are sufficiently detailed so that the geologic map may serve the purpose of the prospector as well as outline the important features of the geology.

Mr. Knopf's studies show that the ore bodies occur in intrusive rocks which are partly of post-Jurassic or post-Lower Cretaceous age. This is confirmative of the views previously held, of which definite proof was lacking. It affords additional evidence of the synchroneity of the mineralization of south-central Alaska with that of the Mother Lode district of California. This work also proves that the sediments and associated greenstones of the Juneau gold belt previously assigned to the Carboniferous are in part at least Mesozoic.

This report is based on studies made in such detail as the physical conditions permitted. The fact that none of the mines were in operation hampered to a large degree the investigations of the ore bodies. If mining develops in this field to the extent which seems warranted by the knowledge of its auriferous deposits, the time will come when a more exhaustive study of the ore bodies should be undertaken.

THE BERNERS BAY REGION, ALASKA.

By Adolph Knopf.

INTRODUCTION.

The Berners Bay region forms the northwestern extremity of the long zone of auriferous mineralization on the mainland of southeastern Alaska known as the Juneau gold belt. This belt has a total length of 100 miles and extends southeastward to Windham Bay, 60 miles southeast of Juneau. A large number of prospects are scattered along the gold belt, but at two localities, Juneau and Berners Bay, there is a marked clustering of producing mines or of potentially productive ore bodies.

The famous Treadwell group of mines, the Perseverance mine, and other properties of great possibilities are located in the Juneau region; a large number of auriferous lodes, although none are comparable in magnitude with those of the better-known properties of the Juneau region, are massed in the Berners Bay region—a comparatively small area—and on account of the favorable topographic conditions make that region an attractive mining field.

The general geologic features of the Juneau gold belt as a whole have been described by Spencer.[a] During his reconnaissance of the gold belt in 1903 only two or three days could be devoted to the Berners Bay region, but that brief study sufficed to bring out the broader facts concerning the ore bodies. In the same year he completed a detailed geologic investigation of the environs of Juneau and was able to publish a geologic map on the scale of 1 mile to the inch to accompany his report. The present study, undertaken in the year 1909, is part of the plan that contemplates a detailed investigation of the northern portion of the Juneau gold belt, to connect with the earlier detailed work of Spencer in the vicinity of Juneau.

Field work on the Berners Bay region was commenced by the writer on May 25, 1909, and completed July 6, 1909. The conditions under which it was carried on were not of the most auspicious character. On account of the unusually late season snow lay on the mountains above an altitude of 1,000 feet during the greater

[a] Spencer, A. C., The Juneau gold belt, Alaska: Bull. U. S. Geol. Survey No. 287, 1906.

part of the time. The rocks are obscured as a rule by a dense growth of moss and other vegetation, and exposures are rare between the shore and the timber line. Nevertheless it is believed that the broader distribution of the rock types is indicated with sufficient accuracy on the geologic map accompanying this report (Pl. II). The general cessation of all mining activity in the region, the absence of everyone familiar with the underground development, and the inaccessible condition of many of the mines precluded as complete a study of the economic geology as might otherwise have been possible.

HISTORY.

Gold ore lodes were first discovered in the Berners Bay region in 1886 or 1887.[a] According to local report float was found by prospectors at the mouth of Sherman Creek, and this led to the discovery of ore bodies outcropping in the upper portion of the drainage area of this stream. In 1890 a settlement known as Seward City was started on the shore of Lynn Canal at the mouth of Sherman Creek,[b] and enjoyed an ephemeral prosperity during the middle of the last decade of the nineteenth century. The settlement, now nearly deserted, is known as Comet, the name Seward having been adopted by an important town on Resurrection Bay on Kenai Peninsula.

Between 1890 and 1900 five stamp mills aggregating 80 stamps were erected in the region. Owing to a variety of causes, they are now all idle. In 1905 the Berners Bay Mining and Milling Company, which controlled one of the most productive mines in the region and which held other valuable properties, became involved in financial and legal difficulties. A protracted litigation ensued which extended through a number of years, and final adjudication was not rendered until near the close of 1909. It was reported in March, 1910, in current numbers of the mining periodicals that the property had been sold at marshal's sale for $800,000 to the International Trust Company, of Boston. Development of the ore bodies and rehabilitation of the plant and tramways will undoubtedly soon be undertaken and a period of increasing production may be anticipated.

PRODUCTION.

The total production of the Berners Bay region up to the close of 1909 has been approximately $1,100,000. Two mines, the Comet and the Jualin, have furnished almost the entire output. The largest output for any single year was that of the year preceding June, 1895, when the Comet mine is reported to have yielded over $200,000.[c]

[a] Garside, G. W., Trans. Am. Inst. Min. Eng., vol. 21, 1893, p. 822.
[b] Alaska: Eleventh Census, 1893, p. 234.
[c] Becker, G. F., Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1897, p. 77.

GEOGRAPHY.

SITUATION OF THE REGION.

The Berners Bay region, which takes its name from a sheet of water 4 miles wide indenting the northeast side of Lynn Canal, is situated 45 miles northwest of Juneau, the capital of Alaska. The term "Berners Bay region" would naturally include all territory contiguous to the bay, but for the purposes of this report, as in popular usage, the name is applied to the long, tapering peninsula and its mountainous background that lie between Berners Bay and Lynn Canal (fig. 1). The areal extent is approximately 50 square miles.

The region is easily reached by water from Juneau. Local steamers plying on a weekly schedule between Juneau and Skagway call

FIGURE 1.—Sketch of Berners Bay region.

regularly at Comet, on Lynn Canal, which is the only settlement in the district. Although no post-office is maintained at Comet, a weekly mail service is furnished by the Post-Office Department.

PHYSICAL FEATURES.

Berners Bay, which was named by Vancouver in 1794, is a broad and deep indentation from Lynn Canal, in latitude 58° 42′ north and longitude 135° west, and lies between Point St. Mary on the north and Point Bridget on the south. The head of the bay is marked by extensive tidal flats formed by the distributaries of Berners River, which enter from the north, and by other large streams of glacial origin, which enter from the east and northeast. Harbors are not common in the bay, but a bight known locally as the Jualin cove affords safe anchorage for large craft.

Lynn Canal, or Lynn Channel, as it was named by Vancouver, flanks the region on the west. Although deep water can be found near shore, there are no harbors affording protection from storms. Lynn Canal is a magnificent fiord, 6 miles wide here, and is the highway of all commerce entering Alaska and the Yukon by way of Skagway.

The Berners Bay region is characterized by abrupt topographic relief (Pl. I). The northern part consists of a rugged assemblage of precipitous peaks which rise steeply from the shore of Lynn Canal to heights of 5,000 feet. The most notable of these form a group known as Lions Head Mountain, whose serrate profile is said to show, when seen from Chatham Strait, a resemblance to a couchant lion. Toward the south the altitudes become lower and the profiles of the mountains become smoother and rounder, until near the tip of the peninsula the low hills scarcely attain an altitude of 500 feet.

The streams on the peninsula are short, but on account of the heavy rainfall they carry relatively large volumes of water. Johnson and Sherman creeks are the largest, and they are also the most important because of the fact that most of the properties are located in their drainage areas.

Johnson Creek heads in an amphitheater of ideal symmetry lying under the shadow of Lions Head Mountain and flows southeastward through a U-shaped valley, emptying into Berners River near the head of the tidal flats of the bay. Its total length is only 4 miles. The lower course is broken by a waterfall 75 feet high and affords a favorable site for the development of hydroelectric power.

Sherman Creek is a short stream heading opposite Johnson Creek and flows northwestward into Lynn Canal. It is fed by numerous small tributaries cascading from the high mountains that flank the stream on its north side. Below an altitude of 500 feet Sherman Creek is intrenched in a narrow gorge.

CLIMATE AND VEGETATION.

No climatologic data concerning the Berners Bay region are available, but the records for Juneau and Skagway will serve to give a general idea of the climatic conditions. As shown by the subjoined table, which was furnished by the courtesy of the Weather Bureau, the total precipitation is considerably less at Skagway than at Juneau. Although Berners Bay is approximately midway between these two cities, the climatic conditions seem to be closely similar to those obtaining at Juneau.

Climatologic data for Juneau and Skagway, Alaska.

Station.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Mean maximum temperature.													
Juneau	32.9	34.3	39.8	47.6	55.9	62.7	64.6	61.4	55.6	48.3	40.5	35.9	48.3
Skagway	24.9	27.6	35.8	47.9	60.7	66.7	68.5	64.1	56.5	46.1	36.7	31.3	47.2
Mean minimum temperature.													
Juneau	24.2	24.2	28.7	34.8	40.8	46.3	49.6	48.2	44.0	38.1	30.3	27.2	36.4
Skagway	15.9	18.1	22.2	32.4	39.2	46.3	48.2	47.3	42.0	35.8	28.5	23.3	33.3
Mean temperature.													
Juneau	28.5	29.3	34.3	41.2	48.4	54.5	57.4	54.8	49.8	43.2	35.5	31.9	42.4
Skagway	20.5	22.9	29.0	40.1	49.9	56.5	58.7	55.7	49.3	40.9	32.6	27.3	40.3
Maximum temperature.													
Juneau	50	51	61	63	80	84	88	82	74	68	60	60	88
Skagway	47	49	63	62	94	90	92	89	76	63	56	57	94
Minimum temperature.													
Juneau	−10	−4	−5	13	24	31	38	36	31	20	−1	1	−10
Skagway	−21	−9	−10	9	25	33	37	31	26	12	4	−4	−21
Mean precipitation (inches).													
Juneau	7.87	4.75	4.86	5.58	5.40	3.97	4.53	7.08	11.16	10.14	8.54	7.24	81.12
Skagway	1.20	1.43	.56	1.78	.68	.90	1.13	1.45	2.65	4.76	3.50	2.76	22.80
Mean snowfall (inches).													
Juneau	32.9	23.1	11.7	4.8	0	0	0	0	0	1.3	6.6	30.1	110.5
Skagway	11.0	3.6	1.2	.9	0	0	0	0	0	2.8	10.4	12.2	42.1
Average number of days with precipitation.													
Juneau	17	12	14	18	16	13	14	17	20	21	19	19	200
Skagway	6	4	4	7	4	5	5	7	10	14	10	9	85

Period of climatologic records, Alaska stations.

	Years.
Juneau:	
1890–1891	2
1899–1908	10
Total	12
Skagway: 1899–1908 (record missing from September, 1900, to April, 1902)	8

The region is well forested with spruce and hemlock. The timber line (the limit of erect tree growth) reaches 2,500 feet above sea level along Lynn Canal, but stands several hundred feet lower on the mountains flanking Berners River on the west. In most places a growth of low contorted forest extends a few hundred feet above timber line. As a rule, the timber forms open stands, and the largest and finest trees, many of which attain a diameter of several feet, are found in the alluvial bottoms bordering Berners River. The undergrowth is rank and luxuriant and in many places forms impenetrable thickets. Alder and devil's club are particularly common, but many other kinds of shrubby growth occur.

GLACIATION.

A few small glaciers are left in the region and their distribution is indicated on the map (Pl. I). On the Lynn Canal side they have nearly disappeared, lying only in the amphitheaters at the heads of the high hanging valleys. On the Berners River side they are much larger and descend considerably farther from the gathering grounds—a difference that seems to be due to the diminished insolation on the north side of the range.

The only moraine in the region is found at 3,300 feet elevation in the cirque above the Ivanhoe mine. It consists of blocks of amygdaloid, and is 20 or 30 feet high, but the glacier which deposited it has retreated from it, so that it is no longer in process of accumulation.

During the recent geologic past great ice streams flowed down the troughs of Lynn Canal and Berners River and covered the larger part of the region under ice. Along Lynn Canal diorite erratics up to 6 feet in diameter were found east of Point Sherman at an altitude of 1,000 feet, and evidence of powerful glacial abrasion occurs up to 2,550 feet above sea level. Along Berners River roche moutonnée surfaces persist up to 2,500 feet.

In general, evidence is abundant as to the former glacial occupation of the region, but observations bearing on the maximum thickness of the trunk glacier that formerly occupied Lynn Canal are not so readily obtained. The data at hand indicate that the minimum thickness, measured from present sea level, was 2,600 feet; from data procured south of Berners Bay, 3,400 feet appears to be a maximum measure of the thickness of the former ice mass.

OUTLINE OF GEOLOGY AND ORE DEPOSITS.

The sedimentary rocks of the Berners Bay area consist of an interstratified series of slates and graywackes, named the Berners formation because it is well exposed across the strike on both shores of Berners Bay. The formation occupies the larger part of the area and lies between the high mountains and Lynn Canal. The strata have been intensely folded, but as a rule strike northwest and southeast and dip steeply northeast. Fossil plants, consisting chiefly of ferns, were found in the rocks on the east side of Berners Bay and indicate that the formation is of Jurassic or Lower Cretaceous age.

A belt of much altered basic lavas, which forms Lions Head Mountain and the high peaks north of Independence Creek, extends northwestward from Berners River to Lynn Canal. The ancient volcanic rocks are commonly amygdaloidal and contain numerous amygdules of epidote. During the time that has elapsed since the lavas were erupted they have undergone many vicissitudes; some which originally were diabase porphyries now resemble fine granular diorites, owing to the fact that the pyrogenic augite has been converted to fibrous hornblende; others have been rendered partly schistose, forming hornblende schists, and subsequently they have been recrystallized around the borders of an intrusive mass of diorite. In consequence of the various kinds of metamorphism to which they have been subjected their originally volcanic character is in many places highly obscure.

Some felsitic or rhyolitic dikes and sills occur with the amygdaloids, in places cutting across the bedding and in places lying between the volcanic sheets. They are light-colored rocks of dense, flintlike texture, and weather white on exposed surfaces. They range in thickness from a few feet to about 100 feet.

The northeastern part of the region is underlain by quartz diorite gneiss, a part of the granitoid core making up the axial mass of the Coast Range. On the west side of Berners Bay the gneiss lies in contact with the amygdaloids; on the east side it intrudes the rocks of the Berners formation. At some time after its intrusion the quartz diorite was rendered coarsely schistose by the action of powerful stresses, as is shown by the partly crushed character of its component minerals when viewed under the microscope.

A mass of diorite, named the Jualin diorite because it is well displayed at the Jualin mine, occupies the basin of Johnson Creek and the upper portion of that of Sherman Creek. It is a grayish rock, composed essentially of plagioclase feldspar, hornblende, and biotite, and ranges in texture from rather fine granular to coarse granular. A small area of heavy black rock composed mainly of hornblende—a coarse hornblendite—is associated with this variety of diorite near Berners River.

The Jualin diorite is undoubtedly of younger age than the quartz diorite gneiss and has escaped the widespread crushing to which the older rock was subjected. It is intrusive into the slates and graywackes of the Berners formation and into the series of basic amygdaloids. It has produced some contact alteration of the sedimentary rocks, but has effected more profound changes in the volcanic rocks, so that their original characteristics are locally obliterated.

The general geologic history of southeastern Alaska suggests that the irruption of the quartz diorite and the Jualin diorite took place during one broad epoch of intrusion, which so far as now known extended through the greater part of the Jurassic period. At Berners Bay powerful deformational forces have been operative between successive intrusions.

The Jualin diorite is the most important rock in the region from an economic point of view. The main ore bodies, in both point of size and of content, lie within the area underlain by it.

The ore bodies are auriferous deposits, of which the larger number are either well-defined fissure veins or irregular stockwork deposits. The fissure veins range up to 15 feet in thickness, but the average vein is 5 feet thick; the stockworks range up to 80 feet in thickness. The mineralogy of the ores is exceedingly simple; the gangue material is quartz with subordinate calcite, and the principal metallic sulphide is pyrite with which are minor amounts of chalcopyrite, galena, and sphalerite. Gold is rarely seen.

The wall rock of the ore bodies has been affected by a locally intense hydrothermal metamorphism, the characteristic feature of which is the production of albite, especially in the small veinlets that penetrate the altered wall rock. This metamorphism is similar to that in the Juneau region, notably like that which has transformed the Treadwell albite-diorite dike into an auriferous lode. The ore bodies are therefore of deep-seated origin, and a magmatic source for the vein-forming solutions is regarded as probable. General considerations indicate that the deposits are likely to extend downward to the limits of profitable mining.

During the recent geologic past the region was affected by a powerful glacial erosion, so that the ores now exposed at the surface are of primary origin.

GENERAL GEOLOGY.

BERNERS FORMATION (JURASSIC-CRETACEOUS).

GENERAL CHARACTER AND DISTRIBUTION.

A sedimentary formation consisting predominantly of slates and graywackes occupies the largest part of the Berners Bay area. Some basaltic greenstones and quartz porphyry schists are associated with it, but are of small importance. The slates comprise in the main highly cleaved black clay slates, but include some of green and to a less extent some of red color. The graywackes are intimately interstratified with the slates in beds ranging from a few inches to 8 feet or more in thickness, and are commonly of a gray or greenish-gray color. They are roughly schistose and in the thicker beds nearly massive.

In places the graywackes constitute the bulk of the formation and comprise a thick succession of heavy beds separated only by thin beds of slate. This massive development of graywacke is particularly well shown toward the south end of the peninsula.

The general strike of the rocks is northwest and southeast, and the dip is steep to the northeast, averaging 70°. Locally high dips to the southwest occur.

The rocks of this formation are splendidly displayed along the west shore of Berners Bay and along Lynn Canal from Point St. Mary to the mouth of Independence Creek. Topographically they form the lower-lying parts of the region, and the boundary between the sedimentary slate and graywacke formation and the igneous rocks also separates the area of the bold craggy peaks from the lesser mountains and hills that make up the southern part of the peninsula.

The formation is also finely exposed on the east shore of Berners Bay, where it includes, however, an important series of augite melaphyres[a] and related pyroclastic rocks. The volcanic member attains its main development as a narrow belt fringing the shore of Lynn Canal from Auke Bay to Point Bridget on the east side of Berners Bay. The nonappearance of this belt on the west side of Berners Bay is probably due to the fact that the strike carries it to the west of Point St. Mary.

On account of the thick carpet of moss that is everywhere prevalent below timber line the sedimentary rocks are poorly exposed inland, and the internal structure of the formation can not be unraveled. In the shore cliffs, however, it can be seen that the rocks have been profoundly folded and closely compressed, and that the axes of folding have also been acutely folded, and that in places they pitch vertically. In consequence of this severe folding of the axes it happens that at many places closely adjacent strata show an angular discordance of strikes. Ordinarily this would be taken to indicate faults of some magnitude, but along the beach, where the geologic relations are perfectly exposed, it can be seen that this feature is due to the vertical attitude of nearly appressed folds.

Subsequent to the complex folding of the rocks a cleavage was induced in them, which commonly coincides with the stratification and trends N. 45° W. (true). In places, such as in the arches of those folds which are standing on edge, the cleavage is conspicuously across the bedding. The cleavage, therefore, rather than the stratification, is the most constant structural feature of the formation.

An enormous amount of quartz veining in the form of stringers following the foliation of the rocks has affected the slates and graywackes, but the amount of pyritic mineralization of these veinlets is nearly insignificant.

[a] This term is used in a purely descriptive sense, as advocated by Pirsson in "Rocks and rock minerals."

PETROGRAPHY.

The graywackes typical of the region consist of gray or greenish-gray rocks in which none of the mineral constituents are discriminable by the eye. Some, however, contain innumerable small fragments of black slate, and isolated beds are found that contain angular fragments of slate several inches long. A more or less thorough schistosity has been impressed upon the graywackes, the perfection of which increases as a rule with the thinness of the beds and the fineness of grain of the component materials. Some of the more highly foliated varieties can not be distinguished by the eye from sheared igneous rocks.

Under the microscope the graywackes are found to consist largely of altered fragments of plagioclase, some of which is referable to Ab_7An_3, embedded in an argillaceous matrix which is somewhat chloritic. The entire absence of quartz in typical graywackes taken from several localities—the mouth of Independence Creek, Jualin Cove, and others—is rather remarkable. Many of the feldspar fragments are partly bounded by crystallographic outlines and show rounded corners; others are highly angular. Fragments of andesitic rock and slivers of slate and possibly other sedimentary rock are of occasional occurrence. Numerous fragments of augite are present in the rock from Jualin Cove, and in the graywackes on the east side of Berners Bay this mineral, or what appears to be its metamorphic equivalent, fibrous hornblende, occurs in quantities appreciable to the eye. Other minerals found in subordinate amounts are calcite, epidote, hornblende, pyrite, magnetite, and apatite. In certain beds, however, calcite becomes an important constituent.

The slates require no particular description. Black or bluish-black clay slates predominate. Locally, as in the gorge of Sherman Creek, they are characterized by a brilliant black luster due to the presence of finely disseminated graphite. Slates of green color are found in small amounts at many places throughout the region, and are particularly well exposed on both sides of Berners Bay. They are more massive and less fissile than the black slates.

A rock of somewhat marked individuality belonging to the class of graywacke slates has a scanty distribution in the Berners Bay region but becomes increasingly prominent as a member of this formation in its extension to the southeast, and therefore deserves mention here. In its general aspect this rock resembles a black clay slate, but differs from that in containing numerous small augen of quartz and of a black glassy cleavable mineral, the presence of the augen producing a porphyritic effect. In thin section the black glassy mineral proves to be a feldspar whose color is due to the infiltration of carbonaceous material. The quartz is seen to show strong undulatory extinction. These two constituents rest in a thoroughly schistose matrix of chlorite, quartz, and carbonaceous matter, throughout which is scattered a small amount of accessory pyrite.

AGE AND CORRELATION.

This formation was regarded by Spencer as the northwestern extension of the slate-greenstone band of the Juneau region, and on account of the presence of fossils found in intercalated limestones at Taku Harbor, which is 25 miles southeast of Juneau, was believed to be of Carboniferous age.

Some fossil plants were collected during the present investigation from the east side of Berners Bay just north of Sawmill Cove. The rocks here consist of an interdigitating series of thick lenses of graywacke and argillite standing on edge. The graywackes show cross-bedding and the argillites are ripple marked. The argillaceous rocks are as a rule too highly cleaved to have retained the imprints of leaves, which are now commonly represented by graphitized flakes. Leaf-bearing beds seem to be scarce, and the best fossils collected were obtained from a roughly schistose argillite which was gashed by quartz veinlets. F. H. Knowlton, of the United States Geological Survey, reports on the plants as follows:

This material is very difficult to study, for practically all traces of nervation are absent and dependence must be placed on outline, which has obviously been more or less modified by pressure. With these limitations in mind, I think I have been able to demonstrate the presence of *Taen iopteris*, *Asplenium* or *Dicksonia*, *Thinnfeldia*(?) and possibly another fern something like *Dryopteris*.

The choice appears to lie between Jurassic and Lower Cretaceous, and if what has been supposed to be *Taeniopteris* is really such the odds favor the former. I have not found anything that can be identified as a dicotyledon, which also is favorable to the probability of its being Jurassic. Although the evidence as adduced is not very strong and the identifications are tentative, it seems most probable that they are of Jurassic age.

According to this determination the rocks of the Berners Bay region are to be correlated in an approximate way with the *Aucella*-bearing terrane found by C. W. Wright on Admiralty Island.[a] This is regarded as of Lower Cretaceous or possibly Upper Jurassic age. The lithology is described as including conglomerates, graywackes, and slates. The Admiralty Island rocks were probably laid down subsequent to the intrusion of the Coast Range diorites, though this is a moot point in the geology of southeastern Alaska; the rocks of the Berners Bay region are predioritic. The invasion of the province by the plutonic masses of the Coast Range is the most important event in the geologic history of the region, and the determination of the exact stratigraphic relations existing between these two terranes is therefore a problem of prime importance.

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[a] Bull. U. S. Geol. Survey No. 287, 1906, p. 144.

DIKES.

Under this heading are described various minor bodies of igneous rock of widely diverse characters that occur within the area of the slates and graywackes. The diorite porphyry dikes that are found as offshoots from the main mass of the Jualin diorite are not discussed here.

In a prospect trench dug in the boss in the lower part of the valley of Johnson Creek is exposed a quartz porphyry schist. The relation to any incasing rocks is effectually concealed under a growth of moss. The quartz porphyry schist is a thoroughly foliated rock of light-greenish color and of oily appearance. On jointage surfaces cutting across the schistosity can be seen numerous quartzes, more or less bounded by crystal faces, resting in a dense matrix. Rocks of this character were not observed elsewhere in the region, nor have they been previously noted in the Juneau gold belt. Under the microscope some of the quartz phenocrysts prove to be characteristically embayed, and this feature affords a most convincing criterion of the originally igneous character of the rock. Feldspar phenocrysts occur but are obscure; epidote pseudomorphs, apparently after hornblende, are found. These constituents are embedded in a highly schistose matrix of sericite and quartz. Titanite in typical wedge forms is a fairly abundant accessory, and apatite, in unbroken prisms where lying in the lee of phenocrysts, is of sporadic occurrence and is especially common in the epidote pseudomorphs. Calcite, pyrite, and tourmaline are present in small amounts.

Some thin dikes of lamprophyric character are occasionally found. Two were noted injected parallel to the stratification along the shore of Lynn Canal near the mouth of Independence Creek. They are dark, heavy rocks, rudely schistose, and the dikes show dense chilled borders. Numerous crystals of augite constitute the sole phenocrystic constituent; abundant idiomorphic augite, though the individual crystals are not of uniform size, occurs in the groundmass. Some laths of highly pleochroic biotite and a little brown idiomorphic hornblende appear also, and labradorite forms an interstitial filling. Magnetite is present as an accessory, and calcite, chlorite, and pyrite are secondary minerals.

On the east side of Berners Bay one of these lamprophyric dikes was noted which seemingly consists mainly of pyroxene phenocrysts. Under the microscope, however, it was found that the pyroxene had been completely transformed into fibrous amphibole, typical pyroxene cross sections showing pleochroism and characteristic amphibole cleavage. The original character of the groundmass is undecipherable from the new growth of amphibole and calcite.

North of the Portland mill on the shore of Lynn Canal a dike of diorite porphyry 50 feet thick is well exposed. This rock is rendered highly porphyritic by the presence of numerous prisms of hornblende, ranging in length from 1 inch down; no other phenocrysts are present. The matrix is gray in color and aphanitic in texture; microscopically it proves to consist mainly of much altered plagioclase.

BASIC VOLCANIC ROCKS.

GENERAL CHARACTER AND DISTRIBUTION.

A series of ancient lavas, mainly of basaltic character, form a belt trending northwestward from Berners River to Lynn Canal. These old volcanic rocks make up the mountainous mass known as the Lions Head and form the precipitous peaks flanking Lynn Canal north of Independence Creek. Brown, red, greenish-blue, and other dark hues are the prevailing colors. As a rule the rocks are conspicuously spotted with yellowish-green amygdules of epidote, and as this is in places their most prominent feature they may conveniently be called epidotic amygdaloids. Sporadically the amygdules carry a small amount of chalcopyrite.

This volcanic series consists almost wholly of a superposed succession of lava flows. Intercalated sheets of breccia were observed at only one locality. The bedded character is commonly obscure, but occasionally sheets differing in color and texture can be found in juxtaposition. These contacts may in places be rendered conspicuous by the highly amygdaloidal character of the marginal portion of one or the other of the lava sheets. In such places the structure can be determined, and where thus measured it is found to strike northwest and southeast and to dip 70° N., coinciding therefore with the general structural trend of the region.

In places the rocks exhibit a rough schistosity, which is best developed near the quartz diorite gneiss bordering them on the northeast. There they approach hornblende schists in structure and composition. The schistosity coincides in direction with the bedding.

PETROGRAPHY.

Some variation in the appearance of the basalts is noticeable from place to place, but on the whole the differences are mainly due to the different kinds of metamorphism to which the various rocks have been subjected.

The basalts so well exposed along Lynn Canal north of Independence Creek are dark greenish-gray rocks, nonporphyritic and fine textured. They are highly amygdaloidal, epidote being most commonly distinguishable as the filling of the vesicles, and quartz more rarely. Microscopically they prove to be plagioclase-augite rocks of doleritic texture. Little or none of the augite has escaped alteration to epidote and chlorite, and the numerous amygdules that occur throughout the rock are filled with the same minerals.

Rock taken above the Ivanhoe mine at an altitude of 3,100 feet is coarser textured and, on account of the abundance of ferromagnesian mineral in it, resembles a dark-colored fine-granular diorite. It contains scattered amygdules of epidote. Under the microscope large sporadic phenocrysts of plagioclase are found to lie embedded in a coarse ophitic matrix, but instead of augite brown amphibole appears. This amphibole occurs also in tufts and irregular aggregates of fibers in the feldspars, and the ends of the large hornblendes fray out in bundles of diverging prisms. Granular epidote is commonly associated with the amphibole. These features clearly indicate the derivative origin of the amphibole and show that the rock was originally a vesicular diabase porphyry.

Rocks of this character are the prevalent variety in the region. Toward the northeast, as already stated, they take on a schistose structure, and the microscopic diagnosis is as a rule insufficient to establish their volcanic character. The field evidence, however, is conclusive on this point.

Certain rocks from Independence Gulch prove to be amygdaloidal andesites. They carry numerous small, rather inconspicuous feldspar phenocrysts in a groundmass which is of denser texture than that of the basalts. The multitude of yellowish-green amygdules is the most striking feature of the rocks. The feldspar, when examined optically, proves to be andesine; the groundmass consists of forked feldspar microlites embedded in a decomposed glassy base. The amygdules are filled with epidote and subordinate chlorite.

CONTACT-ALTERED PHASES.

The amygdaloids have been invaded by the Jualin diorite and considerable changes have been produced in them around the borders of the intrusion. These changes consist mainly of a recrystallization, during which the grain of the volcanic rock has become sufficiently coarse to be perceptible to the eye. The metamorphism is most pronounced in those places where the rock is pierced by dikelets, and the resulting product may resemble a hornblende-rich diorite. In places the intrusive diorite has caught up fragments of the basalts and has recrystallized and partly dissolved them, so that a most heterogeneous sort of rock has been produced which is of very erratic composition and appearance. These features are particularly well shown between the upper and lower workings of the Kensington mine.

In general the principal effect has been to produce a rock in which hornblende is the most abundant constituent. The structure is that typical of contact-metamorphic rocks; the larger mineral individuals show a spongiform development, and droplike particles of one mineral are commonly included in the other. The fibrous, weakly pleochroic amphibole has been converted into a compact, strongly pleochroic brown-green hornblende; the feldspar, which is commonly subordinate, is clear, glassy, and largely unstriated, and ranges from $Ab_{67}An_{33}$ to $Ab_{60}An_{40}$. Magnetite is relatively abundant. In some rocks biotite, which nowhere in the region is a pyrogenetic constituent of the basalts, is developed as a product of contact metamorphism.

AGE.

The contact between the bedded volcanic rocks and the Berners formation is hidden by vegetation and talus slopes, so that no inferences as to the relative ages of the rocks could be drawn. Other lines of evidence must be used. An area of basaltic greenstone of obscurely amygdaloidal character surrounded by slates and graywackes occurs on the south side of Sherman Creek, as shown on Plate I. Other such areas may possibly be found, but on account of the poor exposures and dense vegetation no attempt was made to delimit them. Although the contacts were not seen, the amygdaloidal character suggests that the rock is an intercalated flow or series of flows, and inasmuch as it is lithologically similar to the rocks of the volcanic belt of metabasalts, the conclusion seems to follow that all are essentially of the same age, probably Jurassic. The only fact apparently not in harmony with this conclusion is that the augite melaphyres, which clearly form an integral portion of the Berners formation on the east side of the bay, are petrographically different from the epidotic amygdaloids. This difference may be due to the fact that these two volcanic members represent different eruptive periods during the accumulation of the sedimentary formation.

INTRUSIVE FELSITES.

Some felsitic dikes and sills were found associated with the amygdaloids. They are aphanitic flintlike rocks weathering white on exposed surfaces, and some show a well-developed flow banding. Minute quartzes form the main porphyritic constituent, but as a rule are detected only with difficulty. Microscopically the rock shows embayed quartzes and small sporadic plagioclase feldspars resting in a cryptocrystalline groundmass in which there is scattered a little flaky biotite, some magnetite, and accessory zircon.

The intrusive rocks range in thickness from a few feet to 100 feet and are massive even where intercalated between schistose amygdaloids. Similar rocks are known to occur in the vicinity of Skagway, 40 miles north of Berners Bay, where they are associated with a pink quartzose granite that is intrusive into quartz diorite.[a] They are therefore tentatively considered to be the youngest rocks in the Berners Bay area.

[a] Information from L. M. Prindle.

QUARTZ DIORITE GNEISS.

GENERAL CHARACTER.

The northern part of the Berners Bay region is occupied by quartz diorite, which makes up the mountains on both sides of Berners River and extends as far as the eye can see into the glacial fastnesses of the Coast Range. It is a rock mass of uniform character except along the zone bordering the contact. A coarsely schistose or gneissic structure has been developed in the quartz diorite, trending N. 40° W. (true) and dipping steeply to the northeast, and coincides thus in direction with the cleavage displayed by the slates and graywackes. The quartz diorite gneiss breaks parallel to the structure in thick tabular blocks, and in distant views presents the appearance of a stratified formation. It maintains its petrographic character and gneissic structure for many miles to the southeast of Berners Bay and forms, in local parlance, the hanging wall of the Juneau gold belt.

PETROGRAPHY.

The quartz diorite gneiss is a granitoid rock of medium to coarse grained texture, consisting macroscopically of plagioclase, quartz, biotite, hornblende, and sporadic crystals of titanite. The feldspars range from 3 to 5 millimeters in diameter. The foliated structure is readily apparent in hand specimens. Under the microscope the texture is seen to be hypidiomorphic granular modified by cataclastic phenomena. The plagioclase approximates $Ab_{60}An_{40}$, but the average composition of the feldspar is difficult to determine accurately on account of the strongly developed zonal banding. On a section parallel to the brachypinacoid it was found that the large core was $Ab_{57}An_{43}$; this was succeeded by zones alternately more sodic and more calcic, though all were more sodic than the core; the narrow zone next to the outermost, however, was $Ab_{51}An_{49}$ and the broad outermost zone $Ab_{65}An_{35}$. The feldspars are somewhat granulated peripherally. Quartz forms crushed and elongated areas composed of interlocking grains which show strain shadows. Biotite and hornblende, sliced and wrapping around the feldspars, constitute the dark minerals. Orthoclase is present in insignificant amounts or is entirely absent. Titanite, apatite, and magnetite occur as accessory minerals, and secondary epidote, chlorite, and sericite are present in small amounts.

A typical specimen of the quartz diorite gneiss, taken at a distance of over a mile from the contact, was measured according to Rosiwal's method, the traverses being run across the structure, in order to obtain an approximate quantitative measure of the mineral composition. The following percentage composition by weight was obtained:

Mineral composition of quartz diorite gneiss, Berners Bay region, Alaska.

Plagioclase ($Ab_{60}An_{40}$)	51.1
Orthoclase	1.0
Quartz	25.0
Biotite	13.6
Hornblende	4.8
Titanite	1.1
Apatite	.1
Chlorite	1.9
Epidote	.8
Sericite	.6
	100.0

This composition is closely similar to that determined for the average Coast Range intrusive rock in the Ketchikan region [a] and is characterized by the same unusual percentage of titanite.

CONTACT PHENOMENA AND AGE.

The quartz diorite gneiss shows various modifications along its contact with the rocks that it has invaded. On the east side of Berners Bay the gneiss includes for thousands of feet from the contact vast numbers of rock fragments and detached masses of stratified sediments, which show a crumpling in conformity with the structure of the rock inclosing them. These inclusions were highly metamorphosed—a fact of which muscovite, on account of its absence in the truly igneous rock, is the most notable token—and were partly dissolved, so that it is in places impossible to distinguish between original diorite and altered sedimentary rock. Near the main contact the gneiss becomes finer textured and deficient in femic minerals. At other points, however, the gneiss becomes richer in biotite at the contact, and in consequence takes on a more thoroughly foliated structure than ordinarily prevails throughout the main mass. A peculiar-looking rock results, which consists of numerous augen of feldspar embedded in a foliated groundmass of biotite and hornblende. Under the microscope the feldspars prove to be Ab_1An_1; the augen effect is seen to be due to the fact that corners of the feldspars have been rounded off by peripheral granulation. Biotite and hornblende, both sliced, envelop the feldspars. Titanite (much of which is crushed and dispersed), apatite, and magnetite occur as accessory minerals. The basic character of this marginal phase is therefore expressed by the greater prevalence of femic minerals, by the more calcic composition of the feldspar, and by the absence of quartz. This phase of the gneiss does not occur along the contact with the sedimentary rocks, but only in places along the amygdaloids.

[a] Wright, F. E. and C. W., Bull. U. S. Geol. Survey No. 347, 1908, p. 64.

The contact relations clearly prove the intrusive nature of the quartz diorite gneiss. The age indicated is therefore post-Jurassic or post Lower Cretaceous. The quartz diorite gneiss of the Berners Bay region is part of the composite batholith of granitoid rocks that form the core of the Coast Range. Spencer showed that in the Juneau region the period of intrusion was post-Carboniferous and argued that it was subsequent to the deposition of the Lower Cretaceous rocks on Admiralty Island and before the Upper Cretaceous strata were laid down.[a] The Wright brothers, with the same evidence before them, concluded that the intrusions are of pre-Cretaceous Mesozoic age and continued at least to late middle Jurassic time.[b] More detailed work is needed to fix the period of intrusion with a higher degree of finality.

JUALIN DIORITE.

GENERAL CHARACTER AND OCCURRENCE.

The Jualin diorite is economically the most important lithologic unit in the region. It occupies the drainage area of Johnson Creek and the upper part of that of Sherman Creek, and most of the auriferous lodes are located within the confines of this area. The number of lodes is large compared to the size of the area, and the diorite has consequently been subjected to the attack of vein-forming solutions. Its minerals have therefore undergone more or less alteration, and the diorite tends to assume a greenish color, contrasting in this respect with the fresh, unaltered appearance of the quartz diorite gneiss. This alteration is especially noticeable in the narrow northwest end of the diorite area, where the massing of ore bodies is greatest.

The intrusion of the Jualin diorite has produced some contact-metamorphic alteration of the slates and graywackes, but this change is comparatively small in extent. Perceptible changes up to several hundred feet from the contact have been brought about in the metabasalts, as already described.

Dikes or offshoots from the main mass of diorite are found at various places along the contact. They differ somewhat in appearance from the granular diorite, being diorite porphyries, and consist of closely packed phenocrysts of plagioclase and some hornblende in a dense blue matrix.

PETROGRAPHY.

The Jualin diorite is a granular rock, consisting, so far as the eye can determine, of plagioclase feldspar, hornblende, and biotite. It varies from place to place both in mineral composition and in texture. Hornblende is the most prevalent dark mineral, but locally biotite

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a Bull. U. S. Geol. Survey No. 287, 1906, p. 19.
b Bull. U. S. Geol. Survey No. 347, 1908, p. 76.

exceeds it in prominence and in other places fails entirely. Texturally the diorite ranges from finely granular, as at Jualin, to coarsely granular, as at the Kensington mine. As seen in thin section, the diorite displays a hypidiomorphic granular structure. The plagioclase feldspar is a labradorite near Ab_1An_1 in composition and shows idiomorphic development. Hornblende and biotite are the ferromagnesian minerals. Allotriomorphic orthoclase and interstitial quartz are present in subordinate amounts, although at certain localities, as at the Jualin mine, they are sufficiently abundant to cause the rock to approach a granodiorite in composition. Magnetite, titanite, and apatite occur as accessory minerals. Secondary alteration products, such as epidote, chlorite, calcite, and sericite, are everywhere prevalent.

The Jualin diorite is as a rule a massive rock unaffected by the parallel structure exhibited by the quartz diorite gneiss. Locally, as adjoining certain quartz veins, the diorite has been reduced to a schist, and at a number of localities there occur what are locally designated "slate dikes." This misnomer is perhaps sufficiently descriptive of their physical appearance. The center of one of the "dikes" which is about 30 feet thick consists of black, closely foliated schist; laterally this schist, by progressively wider spacing of the foliation planes, grades into the undeformed diorite country rock. The black schist, when examined microscopically, was found to consist largely of albite feldspar with considerable flaky biotite. Calcite is fairly common, and apatite, titanite, and magnetite occur as accessory minerals.

AGE.

The Jualin diorite is younger than the Berners formation, which it intrudes, and as it has escaped the dynamic deformation to which the quartz diorite gneiss was subjected, it is an intrusive mass of later age than that of the great body of granitoid rocks which form the backbone of the Coast Range in this latitude. No evidence is at hand to fix any limit to the length of time elapsing between the two periods of intrusion, but so far as our present knowledge of southeastern Alaska geology shows the interval was not great.

HORNBLENDITE.

A small area of a granular basic rock strikingly different from the Jualin diorite occurs about 2 miles north of the mouth of Johnson Creek. It is poorly and unsatisfactorily exposed on account of the deep growth of moss, the profusion of vegetation, and the talus slopes from the cliffs of Jualin diorite, and its relation to the adjoining rocks was not determined. It may be either a basic phase of the Jualin diorite or an independent intrusion.

The hornblendite is a heavy black rock composed mainly of hornblende. Abrupt variations in texture and composition are of general occurrence and give the rock a wide range in appearance. The hornblende in places forms prisms up to 2 inches in length and is characterized by its brilliant cleavage faces and metallic luster on cross-fractured surfaces. Locally feldspar, in part converted to epidote, occupies the triangular interstices between the hornblende prisms.

THE ORE BODIES.

INTRODUCTORY STATEMENT.

The ore bodies of the Berners Bay region are gold ore deposits of low grade. On the basis of form they may be classified into three varieties—(1) fissure veins, (2) stockworks or irregular masses of diorite ramified by quartz veinlets, and (3) stringer lodes. This threefold division, although of no genetic significance, expresses certain well-marked characteristics of the ore bodies and can in most of them be maintained.

The largest number of ore deposits, as well as those economically most important, lie within the area of the Jualin diorite and are either in the form of fissure veins or stockworks. The stringer lodes are numerous in the slates and graywackes of the Berners formation, but have not yet proved to be of commercial value.

The outcrops of the ore bodies lying below timber line are much obscured by vegetation. Some are completely grown over with moss and have trees growing on the very tops of the ledges; they were therefore most effectively concealed over the greater part of their lengths prior to discovery. Above timber line the exposures, where not hidden by talus slopes, are better. The longest known outcrops range from 1,500 to 2,000 feet.

The deepest continuous development work has attained a depth of 600 feet below the outcrop of the ore body, and one stockwork has been intersected at 850 feet, although the continuity of the deposit has not been tested. At the time of examination the length of any level on the strike of any ore body accessible to the writer did not exceed a few hundred feet.

FISSURE VEINS.

The fissure veins, with few exceptions, are restricted in their occurrence to the area occupied by the Jualin diorite. Most of the ore bodies belong to this type but are exceeded in size by the stockwork deposits. They are simple quartz-filled fractures with well-defined walls. The average vein has a mean thickness of 5 feet; the maximum width of solid quartz known at any point is 15 feet. A marked tendency to swell and pinch gradually along the strike and dip is exhibited by many of the veins, which thereby form, as it were, a connected series of long flattened lenses. The scanty data at hand seem to show that the average length of the longer axes of these lenses is 400 feet. This tendency is in part an original character-

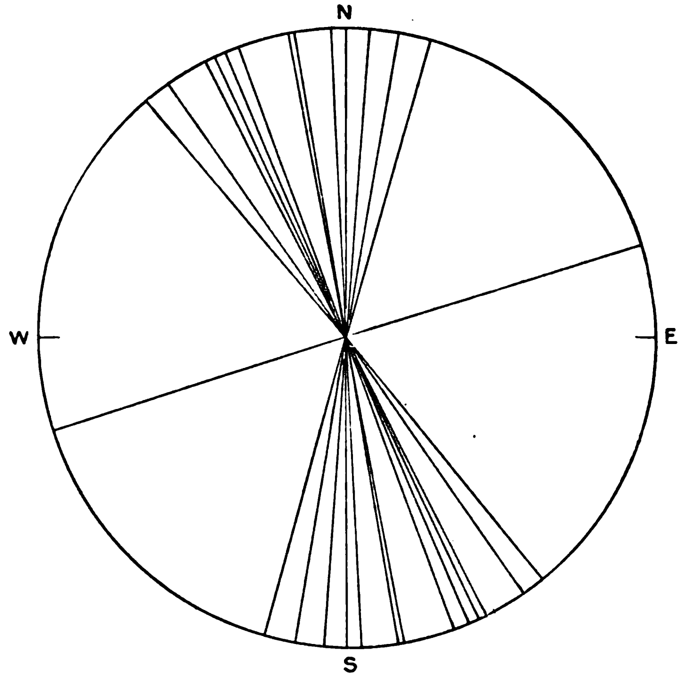

FIGURE 2.—Diagram showing strike of veins.

istic due to the mode of formation of the veins, and is in part due to movements along postmineral fractures making a narrow angle with the plane of the vein. Where the variation in the width of a vein is due to such displacements the swelling or pinching is usually more abrupt than where it is due to the original shape of the fissure.

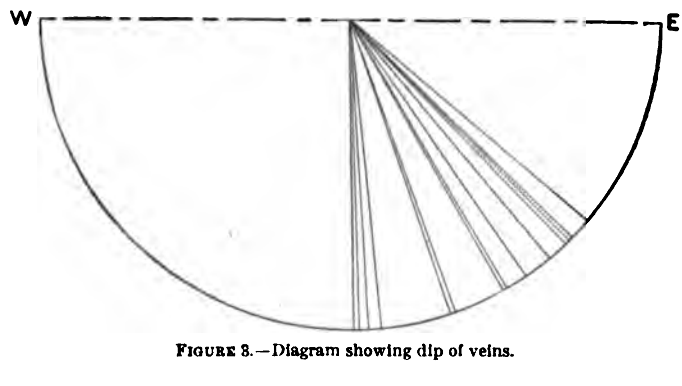

FIGURE 3.—Diagram showing dip of veins.

The strike of individual veins is fairly regular, but no system in the strike of the veins as a whole can be observed. The greater number, however, lie in the northwest-southeast quadrants (fig. 2). The veins dip, almost without exception, to the east or northeast at angles ranging in different ledges from 40° to 70° (fig. 3), but certain veins show as great a variation as this from level to level.

STOCKWORKS.

The stockworks are masses of broken country rock intricately penetrated by quartz stringers. The representatives of this type are not numerous and are of low grade, but on account of the large tonnage of ore which they seem capable of furnishing they appear to form the most valuable asset of the region. They lie in the area of the Jualin diorite. They are irregular in shape and are not bounded by walls. The whole mass of country rock and included network of quartz veins constitutes the ore body, and as the tenor of the ore is dependent on the amount of included quartz, the size of any ore body is determined partly by the dictates of economic expediency—that is, the distinction between what is ore and what is not ore is determined by the working costs. At the Kensington mine, on a study of which our knowledge concerning these deposits chiefly rests, the ore body approximates an ellipse in cross section 160 feet long by 80 feet wide. The quartz veins are most closely spaced near the center of the ore body but toward the periphery become more widely spaced, so that the large amount of barren diorite included in the deposit decreases the assay value of the ore below a profitable limit.

STRINGER LODES.

The stringer lodes are belts of schistose country rock ribboned with veinlets of quartz. They are characteristically developed in the graywackes and slates of the Berners formation and follow the structure of the inclosing rocks. An enormous number of quartz stringers occur in the sedimentary rocks, but few of them carry any metallic minerals, so that comparatively little exploration work has been attempted on them. At a few localities stringer lodes have been partly developed, but not sufficiently to demonstrate economic importance.

At other points in the Juneau gold belt stringer lodes in slate have proved to be of great value, so that the discovery of commercially valuable lodes of this character in the Berners Bay region is not inherently improbable. The general law of the occurrence of stringer lodes in the Juneau gold belt shows that they are most likely to lie along the contact of a belt of slate with a harder bed, which is commonly either a sheet of greenstone or a stratum of graywacke.

MINERALOGY OF THE ORE DEPOSITS.

Introductory statement.—The mineralogy of the ore deposits is extremely simple. In the veins the minerals constitute the material that forms the filling of the fissures; in the stockworks and stringer lodes they include the minerals of the country rock or the minerals derived from their alteration under the action of the mineral-bearing solutions. The variety is not great, nor are the minerals distinguished by any peculiarities of crystallization. Oxidation products are not common.

Gold.—The low-grade ores rarely show any gold visible to the eye. It is reported, however, that gold was found intergrown with quartz in masses of considerable size in pockets in the Comet mine. In the upper parts of some lodes it appears in bright-yellow particles embedded in iron ocher, where it has evidently been derived from the oxidation of a pyritic mineral. At the Jualin mine it is closely associated with chalcopyrite, commonly intergrown, and is with difficulty distinguished on account of the almost identical similarity of color between gold and chalcopyrite. Gold occurs also embedded in calcite.

Copper.—Native copper was not observed in any of the mines, but is reported to have been found in the stream bed of Johnson Creek below the Jualin mine. The presence of chalcopyrite and some of its oxidation products, azurite and malachite, in that lode leaves little doubt that the native metal was derived, like the carbonates, from the oxidation of copper pyrites.

Galena.—The lead-gray sulphide of lead occurs in small particles embedded in the quartz of the veins and stringers. It occurs nowhere in the altered wall rock, differing notably in this respect from pyrite. It shows no crystallographic boundaries, but exhibits the characteristic cubical cleavage.

Sphalerite.—Sphalerite was noted at only two of the properties in the district—the Jualin and the Fremming. At the Fremming it is of yellowish-brown color and occurs together with galena, pyrite, chalcopyrite, and free gold. Minute amounts of black sphalerite occur at the Jualin mine.

Chalcopyrite.—Chalcopyrite, the gold-yellow sulphide of copper and iron, is, next to pyrite, the commonest metallic sulphide in the region. Its presence seems favorable to good values in gold, and gold is often found inclosed in it at the Jualin mine. As a rule, the chalcopyrite occurs embedded in quartz in irregular particles without crystal faces, but where it lines drusy cavities it forms small tetrahedrons. Chalcopyrite may be distinguished from pyrite, with which it may sometimes be confused, by its comparative softness, for it scratches readily, and its deeper yellow color.

Pyrite.—The pale brass-yellow sulphide of iron, pyrite, is the most abundant metallic mineral in the region. Unlike the other sulphides—galena, sphalerite, and chalcopyrite—it occurs both in the vein fillings and in the altered wall rocks. The pyrite is both massive and crystalline; where crystallized it is commonly in the form of striated cubes and rarely, as at the Indiana property, in fine octahedrons.

Quartz.—The principal nonmetalliferous mineral forming the vein-filling material of the region is a white quartz of fairly coarse texture. Some of the veins are characterized by a drusy structure, and in these the quartz is partly bounded by crystal faces, and terminated prisms project into the vugs. The central portion of the Ophir vein contains cavities several feet long, and these are implanted with large glassy crystals of quartz.

Calcite.—Calcite occurs as a subordinate constituent in all the quartz veins but as a rule is prominent only in the stringers. Sparry masses occur in places in the altered diorite wall rock; some is of reddish-brown color, but as it is easily soluble in cold hydrochloric acid, it is probably a ferriferous calcite and not siderite, as was suspected.

Dolomite.—The presence of dolomite is indicated by the microscope as an alteration product of the diorite adjoining quartz veins. It is recognized in the larger aggregates by its strongly curved cleavage and by its tendency to form perfect rhombohedrons scattered throughout the altered diorite. It was positively identified by determining the value of the refractive index ω.

Feldspar.—The feldspar of the Jualin diorite is an important constituent of the stockwork ore bodies, such as the Eureka, the Kensington, and the Johnson. It is a plagioclase (commonly andesine) or labradorite, but instead of showing the white, pearly appearance of ordinary feldspar, it is light greenish and possesses rather an oily luster due to a more or less thorough alteration to sericite. A clear glassy feldspar, which the microscope shows to be albite, is in places associated with the altered plagioclase feldspar, from whose transformation it has been derived by the action of vein-forming solutions. It is also found in microscopic veinlets in the altered diorite along with quartz and calcite or dolomite. Its presence throws important light on the character of these solutions and allies the mineralization with that which has taken place at the Treadwell deposits. Albite has not been noted as a macroscopic component of the larger quartz veins, but its discovery seems not unlikely.

Sericite.—Scales of silvery-white mica occur in the vein quartz, but nowhere in large amount. It is, as already indicated, abundant as a microscopic constitutent of the altered feldspar of the diorite wall rock.

Hornblende.—Hornblende in its unaltered condition is a dark-green or black prismatic mineral, which is a prominent constituent of the Jualin diorite. Under the action of mineralizing solutions it has been converted into epidote and chlorite.

Epidote.—Epidote, a hydrous aluminum silicate of calcium and iron, is a mineral of bright yellowish-green color. It is present in the hydrothermally altered diorite in a finely disseminated condition, and is responsible in considerable measure for the greenish hue that the diorite assumes in the vicinity of the ore bodies.

Chlorite.—Chlorite is a micaceous or foliated mineral of deep-green color. It is abundant in the stockwork deposits as an alteration product of biotite, which is one of the pyrogenetic constituents of the Jualin diorite. It is in part derived also from hornblende. The pyrite in the country rock is commonly associated with chlorite, much of which shows sagenitic webs. The fibers or prisms making up these webs are in some places sufficiently coarse to show the diagnostic properties of rutile, such as deep pleochroism, straight extinction, and relief.

VALUE OF THE ORES.

The ores, if $10 a ton is considered to fix the upper limit in value of low-grade ores, are commonly of low grade. The Comet mine, one of the two largest producers in the region, averaged $9.20 a ton for a production of 50,000 tons. On the other hand, a number of strong fissure veins averaging 5 feet in thickness, from which a considerable tonnage of ore has been mined and milled, have yielded only $3 to the ton—an amount that under present conditions is below the working costs.

The highest grade ore in the region was extracted from one of the veins of the Jualin mine and averaged $30 a ton over a width of 7 feet. It is a noteworthy fact that the ore of this mine is comparatively high in metallic sulphides.

Few data are available concerning the value of the ore of the stockwork deposits. The general rule seems to hold that the values increase proportionately to the size and number of quartz stringers per volume of country rock. The Eureka is said to average $7 a ton over a width of 18 feet, the Kensington from $3 to $5 over a width of 80 feet.

FISSURE AND VEIN FORMING PROCESSES.

The formation of the veins required the intervention of two separate processes—the fracturing and opening of the fissures and the filling of the fissures with quartz and the metalliferous constituents. The second process tends to obscure and obliterate certain of the records of the first.

Some of the veins are in places adjoined by belts of mashed diorite which have the structure of a closely foliated green schist. Fragments of this schist inclosed in the veins prove that the crushing of the diorite took place prior to the introduction of the vein-filling material, but it is improbable that this green schist with its present mineral make-up is the product of the mechanical alteration of the diorite. It has been too thoroughly affected by the ore-depositing agencies to retain its original composition. Viewed under the microscope, the schist proves to be composed largely of altered plagioclase and sericite, with a minor amount of calcite and accessory chlorite, magnetite, and apatite. The green color of the schist is due to the presence of the sericite.

Narrow portions of some of the veins are occupied by schistose diorite or are filled with broken masses of diorite interlaced with quartz stringers. All these features indicate that powerful compressive forces were operative in producing the fractures.

At other points in the region these stresses have produced belts of schist in the diorite, but these schistose zones have remained unmineralized, possibly because they were too tight to furnish free circulation to the ore-depositing agencies. One of the schists—a light-green foliated rock from a zone 10 feet thick in the Indiana tunnel—was found to consist of highly altered plagioclase which is much obscured by sericite and carbonate. The sericite shows no schistose arrangement like that, for example, characterizing deformed quartz porphyries; the carbonate is commonly scattered throughout the feldspars in the form of small rhombohedrons. Both minerals are characteristic of the chemically altered wall rock that adjoins the ore bodies. A number of small radiate groups of bluish-brown tourmaline occur throughout the rock, and pyrite, magnetite, and apatite are present as accessory minerals. The tourmaline was introduced subsequent to the shearing of the rock, and tourmalinization appears to have been contemporaneous with the sericitization and carbonatization.

In addition to the mechanical alteration of the wall rocks, they have been affected by a chemical alteration due to the activity of the agencies that brought in the quartz and metallic minerals. The width of wall rock affected by this alteration varies, ranging up to several feet. The alteration is most intense where the wall rock is irregularly penetrated by stringers branching from the main lode.

The general course of the alteration of the diorite leads to the chloritization and destruction of the ferromagnesian minerals, to the partial sericitization of the plagioclase feldspar, to the formation of albite, and to the introduction of carbonates (dolomitic in part) and pyrite. In short, the diorite is transformed mainly by recrystallization, during which there is some addition of carbon dioxide and sulphur and probably of iron and potash. The process is very similar to that determined for the Treadwell ore deposit by Spencer,[a] who pointed out that, though the occurrence of albite is fairly common in certain types of gold-quartz veins, it had not previously been detected in the metasomatically altered wall rocks of any veins that had been studied. It has been noted by Lindgren[b] to form in albite-rich amphibolites.

The most thorough alteration observed in the Berners Bay region was that adjoining portions of the Bear vein. Here the diorite has been converted into a nearly snow-white rock impregnated with small cubes of pyrite. In thin section this rock is seen to have a crushed granulated structure healed by recrystallization and obscured by metasomatic alteration. Plagioclase is the main constituent and is largely altered. It is sericitized, especially where pyrite has been introduced, and in places contains rhombohedrons of carbonate. Patches of recrystallized clear glassy feldspar, which proves to be albite, occur sporadically. Replaced areas consisting of carbonate that shows strongly curved cleavage, quartz, and subordinate albite are present. The carbonate was proved to be dolomite by determining the value of ω according to Schroeder van der Kolk's method;[c] this value was found to be 1.69.

It is not possible to obtain the fresh diorite from which this wall rock was derived. At 550 feet from the vein the diorite shows numerous hornblende prisms resting in dull-green aphanitic matrix. In thin section this apparent matrix is found to consist of highly altered feldspar and primary interstitial quartz. The feldspar, mainly plagioclase with some orthoclase, is thoroughly sericitized. Epidote, chlorite, and carbonate are common; pyrite occurs sporadically. The presence of magnetite as a relatively abundant accessory mineral is noteworthy. The hornblende which is so readily seen in the hand specimens proves to be considerably altered; the presence of chloritized biotite is suggested but can not be established.

Where the metasomatic alteration has been less intense, as in the diorite of the Kensington stockwork or at the Jualin mine, the altered wall rock consists essentially of an aggregate of sericitized plagioclase and chloritized biotite which shows sagenitic webs. No recognizable vestiges of hornblende are present. In places considerable apatite occurs as an accessory mineral. The veinlets of quartz that traverse this altered rock contain dolomite and calcite, a little sericite and chlorite, and some glassy striated subhedral albite. In places the

[a] Bull. U. S. Geol. Survey No. 287, 1906, p. 113.
[b] Lindgren, Waldemar, Econ. Geology, vol. 2, 1907, p. 11
[c] Determined by E. S. Larsen.

limpid new albite adjoins highly sericitized feldspar, and the contrast between original and secondary feldspar is strikingly apparent. Some of the smaller veinlets are composed entirely of dolomite and albite.

At a greater distance from the ore bodies, hornblende begins to appear in the diorite. It is partly epidotized and chloritized; epidote appears also in the plagioclase, together with carbonate and sericite. The biotite is partly chloritized, commonly around the edges, and contains finely developed sagenitic webs, especially in the chloritized portions. Zoisite is noted here and there. Magnetite appears among the ordinary accessory minerals of the diorite.

The mineralogical study of the metamorphism of the diorite wall rocks shows that where the alteration was most profound the femic minerals, especially the hornblende and magnetite, were destroyed and all traces of their former presence completely obliterated. The iron of these minerals was used to form pyrite; the lime and magnesia of the hornblende to form dolomite. The feldspar has been partly sericitized and recrystallized to albite. The potash of the sericite was, in part at least, furnished by the biotite. Apatite remains throughout the course of alteration. Epidote is not formed in the zone of most intense metasomatism, but appears in the zone of feebler alteration.

The alteration of the wall rock has been mainly in the nature of a chemical rearrangement of the constituent molecules, modified to some extent by the introduction of sulphur and carbon dioxide and by the partial elimination of soda. In general, the amount of pyrite developed in the wall rock seems to have been determined by the amount of iron originally present in the ferromagnesian minerals and magnetite.

The chemical work done by the ore-depositing agencies shows that they were hot ascending solutions carrying carbon dioxide, sulphur (probably as hydrogen sulphide), silica, potash, gold, iron, and several heavy metals in small quantities, and doubtless other constituents that have left no record of their presence because they remained unfixed either in the vein stuff or in the altered wall rocks. At one locality the solutions were capable of causing the formation of tourmaline as well as producing sericitization and carbonatization. The occurrence of this tourmaline tends to corroborate the conclusion previously reached concerning the comparatively highly heated character of the vein-forming solutions. Too weighty a superstructure of argument should not be built on this single occurrence, but it suggests that when the mining development of the region is further advanced and increased facilities for investigation are provided the relation of the tourmalinization and auriferous mineralization can be more firmly established.

ORIGIN OF THE ORE DEPOSITS.

The problem concerning the origin of the ore deposits involves the consideration of two factors—the origin of the fractures and the origin or source of the vein stuff and its metalliferous constituents.

Compressive forces, as indicated by the schistose nature of the wall rocks, caused the initial fracturing of the rocks. The surfaces along which this rupturing took place were not simple planes, but were rather of gently undulating character along both the strike and the dip, as shown by the stoped-out portions of the veins, and subsequent movements along the fractures produced the open spaces in which the quartz and metallic minerals were later deposited.

The fissures show neither conjugate relations nor any other discernible systematic arrangement. In a highly speculative paper Spencer[a] has put forth a conception of the origin of the fissures in the Juneau gold belt, but inasmuch as the conditions postulated in his argument do not exist in the Berners Bay country his ideas can not be applied to that region.

The localization of the largest number of ore bodies in the area of the Jualin diorite is the most striking fact in the geology of the region. It suggests a genetic dependence on that rock mass, but what that genetic relation is can not easily be established.

The mineralogical character of the veins throws no light on the origin of the deposits. The metallic minerals—gold, pyrite, chalcopyrite, galena, and sphalerite—and the gangue mineral quartz all belong to the group of persistent minerals,[b] and are therefore of little genetic significance.

The character of the metasomatic alteration of the wall rock affords a more hopeful line of attack on the problem. The study of that process has shown that the vein-forming solutions were capable of effecting an intense hydrothermal metamorphism, a characteristic feature of which is the development of albite in the altered rock as well as in the narrow veinlets penetrating the altered wall rock. This feature, as already pointed out, allies the character of the mineralization to that which has produced the Treadwell lode, so that this similarity is one of both practical and theoretical significance. The presence of albite appears to be a regional characteristic of the Juneau gold belt, and, on account of the known instability of soda minerals in veins formed at moderate or shallow depths,[c] indicates a deep-seated origin for the gold veins.

The hypothesis of a magmatic origin for the vein-forming waters in southeastern Alaska was first advanced by Spencer[d] and was

[a] Spencer, A. C., The origin of vein-filled openings in southeastern Alaska: Trans. Am. Inst. Min. Eng., vol. 36, 1906, pp. 1211-1216.

[b] Lindgren, Waldemar, The relation of ore deposition to physical condition: Econ. Geology, vol. 2, 1907, p. 122.

[c] Lindgren, Waldemar, op. cit., p. 117.

[d] Spencer, A. C., Trans. Am. Inst. Min. Eng., vol. 36, 1906, p. 971; also Bull. U. S. Geol. Survey No. 287, 1906, p. 30.

based mainly on the facts observed in the Juneau district. These included the relation of mineralization to intrusive rocks, the nature of the metasomatic processes, and the sporadic presence of pneumatolytic minerals in the veins.

All subsequent work has tended to support this hypothesis. The geologic map[a] published on the completion of reconnaissance work in southeastern Alaska shows most strikingly the clustering of mineral deposits along the intrusive contacts of granitoid rocks. The force of this suggestive relation gains cumulative strength when it is found that a similar association exists along the eastern margin of the diorite core of the Coast Range.

It is therefore probable that in a regional treatment of the ore deposits of southeastern Alaska the hypothesis of Spencer embodies an important generalization, the plausibility of which may not always be readily apparent when applied to individual deposits or localities. At Berners Bay the massing of the ore bodies in the area of the Jualin diorite is so striking a feature that a certain mental restraint is required to keep from precipitately embracing the magmatic hypothesis.

The independent evidence that the region as an isolated unit offers to the magmatic hypothesis consists, first, in the spatial relation of the ore bodies to the diorite, and, second, in the character of the metasomatic alteration of the wall rocks. From the present status of knowledge concerning the origin of ore bodies it may be regarded as established that the vein-forming agencies were ascending thermal solutions. That they were released from a cooling magma is strongly suggested but not proved. The tourmalinization effected by solutions essentially similar in composition to those that produced economic mineralization is a fact lending support to the magmatic hypothesis, but in view of the meager distribution of the tourmaline, so far as known, it is one on which much weight can not be laid.

PRACTICAL DEDUCTIONS.

Any enriched surface ores that may have existed within this region have been swept away by the powerful glacial erosion to which the region was subjected in the recent geologic past. The ores exposed at the surface are therefore of primary origin, modified to an unimportant extent by postglacial oxidation, and the outcrop of any ore deposit will furnish a true index of the value of the lode as a whole, depending on whether the distribution of values in the ore is or is not uniform. As some of the veins have been found to be pockety and as many an undeveloped prospect is known from a single outcrop only on account of the generally poor exposures in the region, it

[a] Wright, C. W., Bull. U. S. Geol. Survey No. 345, 1908, Pl. II.

may happen that a surface ore may give results that are either higher or lower than the average value of the whole ore body.

The continuity of the ore deposits in depth is a matter of the highest practical interest. It is dependent on two factors—the persistence of the fissuring and the character or quality of the mineralization. As shown by the microscopic study of the vein-forming processes, the quality of the mineralization is such as to assure its maintenance to a depth which is below the limit of profitable mining. This conclusion is enforced by both theoretical and practical considerations. The Kensington lode outcrops at an altitude of 2,800 feet; the Treadwell, which outcrops near sea level, has been proved to a depth of 1,700 feet without diminution of its values. This gives a known vertical range of practically 4,500 feet through which the auriferous solutions were capable of precipitating gold in the Juneau district. The probabilities are that this is a minimum estimate, but it is perhaps well to point out that this figure is based on the assumption that the ore deposits have not been displaced vertically with reference to each other since they were formed, either by faulting or by crustal warping.

It does not follow, however, that the quantity of mineralization persists downward. This is a function of the extent of the fissuring in depth and the persistence of size of the veins or the amount of veination in the stockworks. These factors can be determined much less satisfactorily than those relating to the quality of mineralization.

It has been pointed out in previous pages that the veins were formed by the movement of the walls past each other along gently sinuous fractures. Pinches and swells are therefore encountered on the levels along the strike of the veins. Similar variation is to be expected vertically also, although development has not yet been sufficiently extensive to demonstrate this as a law.

Inasmuch as narrow portions of the fissures are commonly occupied by masses of schistose diorite which are here and there interlaced with quartz stringers, such schistose zones are worth exploring or drifting on in the chance of striking other valuable ore bodies. This possibility was forcibly illustrated at the Jualin mine, where an 18-inch zone of crushed diorite of most unpromising appearance opened out when followed along the strike into a strong and valuable ore body. That this is no infallible rule, however, is clearly demonstrated by certain fruitless attempts that have been made under its guidance. In the most conspicuous example 500 feet of tunnel was drifted along a schistose zone in the diorite without encountering a ledge. The probability of striking an ore body is apparently strongest in those belts of crushed or sheared diorite that are penetrated by quartz stringers.

On the whole, the downward persistence of fissuring would seem to be proved by the deep-seated origin of the vein-forming solutions, as shown by the alterations that they were able to effect in the wall rocks. The ore bodies will doubtless show variations in size along the dip and strike, but the character of the diorite country rock is favorable to their continuity in depth.

The conclusion that the ore deposits are of deep-seated origin and due to the ascent of thermal waters is ultimately based on empirical generalizations and is independent of any speculative conceptions as to the magmatic origin of those solutions. It therefore rests upon a firmer foundation and lends assurance to the belief that the ore deposits will, as a rule, persist downward below the limits of profitable extraction without essential change of values.

DESCRIPTIONS OF INDIVIDUAL MINES AND PROSPECTS.[a]

The mines and prospects are described in geographic order, those in the Sherman Creek drainage basin being taken up first and those on the Berners Bay side being considered last. A large number of partly developed prospects or locations are not described, in order to avoid a monotonous repetition of uninstructive details.

IVANHOE MINE.

The main tunnel of the Ivanhoe mine is situated 2½ miles northeast of Comet, at 2,350 feet above sea level. This, the upper working, was connected with the stamp mill, which is situated on Sherman Creek at an altitude of 500 feet, by a tramway system consisting of 3,000 feet of cable tram and 2,700 feet of gravity tram. This system has been largely destroyed by rock and snow slides. The mill is equipped with 20 stamps and 8 Frue vanners and houses the compressor plant.

The principal tunnel bears east for 185 feet to a point where it intersects the vein at a depth of 45 feet below the outcrop; a drift opens the vein over a length of 850 feet. At one point ore has been stoped out to the surface, and 3,000 tons was extracted, reported to have yielded about $7,000. The property has been idle since 1903.

The vein averages 5 feet in thickness, ranging from 1 to 9 feet, and is inclosed between well-defined walls. The strike is N. 10° W. and the dip ranges from 30° to 60° E., averaging 50°. The country rock in the vicinity of the Ivanhoe mine consists of altered basalts or diabase porphyries. These are dark-colored fine granular rocks spotted with conspicuous blebs of yellowish-green epidote. The original bedded character of the rocks is obscure, but differences of

a [illegible] for information [illegible] texture can be noted from place to place. The rock 50 feet west of the tunnel entrance is more porphyritic than the prevailing variety. Tabular feldspars one-half inch long form the phenocrysts and are arranged here and there in stellate groups.

HORRIBLE MINE.

The Horrible group of five claims was located in 1896 and was sold late in the same year to the Portland-Alaska Mining Company. Mining operations were begun in the spring of 1897, and an aerial tramway 2 miles long was erected which connected the mine workings with a 10-stamp mill built on the shore of Lynn Canal. Work was suspended during the winter of that year and was resumed only for a short time in 1901.

The mine is opened by a tunnel 400 feet long drifted on the ledge, which strikes north and south and dips steeply to the east. The ore body consists of a quartz-filled fissure whose walls are commonly well defined and which ranges in width from a seam to 10 feet, averaging 5 feet. The quartz is sparingly mineralized with metallic minerals; the only one visible to the eye is pyrite. The country rock inclosing the vein is a green diorite of rather fine texture. The hanging-wall side has been explored by a drift 240 feet long, but no ore body was encountered.

Some stoping was done on the vein and 500 tons of ore was extracted; this is reported to have yielded $1,500 in gold.

OPHIR GROUP.

The Ophir vein outcrops prominently at an altitude of 1,500 feet along the flank of the mountain north of Sherman Creek. Three tunnels have been driven on the property, two of which cut the vein. The third, which is 300 feet long, is planned to undercut the ore body at a depth of 200 feet, but has not been completed. The two upper tunnels are 400 feet apart on the strike of the vein, and drifts aggregating 300 feet have been driven along its course.

The country rock at the Ophir vein is a greenish diorite characterized by an abundance of small black prisms of hornblende. The ore body is a simple quartz-filled fissure vein striking N. 30° W. and dipping on an average 45° E. It ranges in thickness from 2 to 6 feet. The quartz is practically devoid of pyritic mineralization, sporadic particles of iron pyrite only being present. The Ophir vein is rendered notably different from others in the district through the presence of numerous vugs and cavities lined with large glassy quartz crystals.

BEAR MINE.

The Bear mine is situated on the north slope of Sherman Creek at an elevation of 1,350 feet and is connected with the 40-stamp mill of the Berners Bay Mining and Milling Company by a gravity tramway

1,700 feet long. The mine is developed by an adit level 1,100 feet long, which crosscuts the Bear vein 500 feet from the portal and 200 feet below the outcrop. The additional 600 feet is said to have been driven in pursuance of a plan to eventually undercut the Kensington lode at this greatly increased depth. A raise was put through to the surface on the Bear vein and three levels from 250 to 300 feet long have been worked. From these considerable ore has been stoped in places, the stopes reaching the surface. During the years 1895 to 1897 about 5,500 tons was extracted.

The country rock at the Bear mine is a greenish diorite whose green color in due mainly to the presence of finely disseminated epidote and chlorite. The vein trends approximately N. 20° W. and dips somewhat irregularly, from 70° E. at the surface to 40° E. on the adit level. The walls are well defined; the thickness of the vein averages 2 feet on the surface and 5 feet on the adit level. In places the diorite wall rock is highly altered to a snow-white rock cut by quartz stringers and studded with numerous small perfect cubes of pyrite. The vein is practically barren of metallic minerals but carries a small amount of pyrite and chalcopyrite.

Another vein, smaller than the Bear vein, was crosscut by the adit level at 300 feet from the portal. It is from 2 to 5 feet thick, strikes N. 15° W., and dips from 10° to 40° E. About 100 feet of drifts have been driven on the ledge.

KENSINGTON MINE.

The Kensington mine is situated on the north slope of Sherman Creek 2 miles due east of Comet. During the years 1897 to 1900 some 12,000 tons of ore was mined from the outcrop and from shallow underground workings. In 1904 a long crosscut tunnel was driven to prove the persistence of the ore body in depth. Since that time no further work has been done on the property, but on the settlement of certain legal difficulties it will undoubtedly be reopened.

The portal of the crosscut tunnel is situated at an altitude of 2,100 feet and is connected with the gravity tram of the Bear mine by an aerial tramway, but this is now in a state of extreme disrepair. (See fig. 4.) The tunnel, which will serve as the main working adit, is 1,950 feet long, and drifts and crosscuts aggregating 640 feet have been driven to explore and define the limits of the ore body. The upper workings of the Kensington are situated at an elevation of 2,800 feet, or 800 feet above the crosscut tunnel. Here some large, irregular galleries have been stoped out, in places 30 feet high, but none of the tunnels extend over 250 feet into the mountain. Some mining has also been done on the surface croppings 40 feet above the entrance to the tunnels.

The geologic features of the Kensington ore body as shown in the outcrop and in the tunnels on both levels are essentially similar. The ore body consists of an irregular mass of diorite gashed by a multitude of quartz stringers, which range in thickness from a seam to a foot but commonly average a few inches. In plan the ore body, as shown on the main crosscut level, rudely approximates an ellipse 80 feet in width and 160 feet in length, with the major axis trending north and south. The two levels give cross sections 800 feet vertically apart and apparently show that the deposit constitutes an inclined column or chimney of ore dipping 67° E.

The quartz veinlets in the main interlace the diorite irregularly, but show an ill-defined tendency to trend parallel to the major axis of the lode in cross section. They carry pyrite as the only metallic mineral visible to the eye, though a small amount of galena was noted at one point. The diorite adjoining the quartz veinlets is heavily pyritic in places, but more commonly it contains scattered

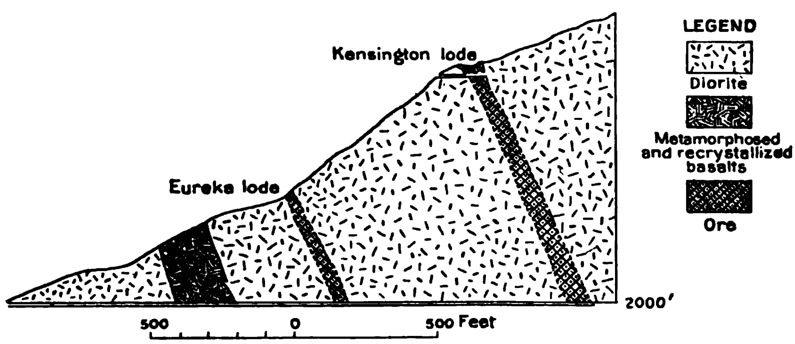

FIGURE 4.—Diagrammatic section along the Kensington tunnel.

grains of pyrite disseminated through it. The diorite has not undergone sufficient alteration from the action of vein-forming solutions to obscure its dioritic appearance. Nevertheless it differs noticeably from the barren diorite, being in general of a greener color—a change that is due largely to the conversion of the lustrous flakes of black biotite to dull-green chlorite. The feldspars are sericitized and other changes have taken place, described in detail elsewhere in this report. The larger stringers are practically solid quartz; the small veinlets, especially those that finger out into the country rock, contain carbonates, with which, as shown by the microscope, is associated some albite feldspar.

A lamprophyric dike 16 inches thick, with strongly chilled margins, was encountered in the north drift on the main crosscut level. It is a dark fine-textured porphyritic rock showing numerous phenocrysts of hornblende. Under the microscope hornblende is found to be the most abundant constituent and to form both the phenocrysts and a large proportion of the groundmass; it is partly epidotized and chloritized. Plagioclase occurs interstitially but is obscured by sericitization; some quartz is associated with it. Titanite is a notable accessory; magnetite occurs sparingly. Pyrite and calcite are sporadic secondary minerals. Such a rock would be designated a spessartite in the classification of Rosenbusch. It is probably related to the dike near the Portland mill described on pages 18-19, which was called there a diorite porphyry but which, as can be seen from the description, has lamprophyric characteristics. The dike at the Kensington mine was intruded before the ore body was formed, so that it is of little practical significance.

The ore body is not defined by walls. The values vary with the abundance of quartz veinlets and are said to range from $3 to $5 a ton for the width of 80 feet. The mill returns are reported to have shown the following distribution of values: Bullion 5 per cent, concentrates 62 per cent, tailings 33 per cent.

EUREKA MINE.

The Eureka lode outcrops several hundred feet below the Kensington and has been undercut by the Kensington tunnel at a depth of approximately 350 feet below the exposed outcrop and 1,300 feet from the mouth of the tunnel. The geologic features are essentially similar to those of the Kensington ore body, but in form the Eureka is longer and narrower. It is 400 feet long on the surface and where intersected by the crosscut is from 30 to 40 feet wide, consisting of a mass of coarse diorite closely interlaced with quartz stringers. No drifting has been done along the lode on the crosscut level. Careful assays across a width of 18 feet are reported to give a minimum value of $6.56 a ton for the ore body as exposed in the Kensington tunnel.

COMET MINE.

The Comet mine is situated near the head of Sherman Creek, the veins outcropping at an elevation of 2,300 feet and the main crosscut entering the mountain at an elevation of 1,650 feet. The property was located in 1890 by six owners, who sold it to Thomas Nowell in 1892. Developments began in 1893, the main crosscut was commenced in 1896, and the property was operated until 1901; since that time it has laid idle, being tied up by litigation. The improvements have gone to ruin, the buildings have collapsed, and the tunnels have partly caved in. The underground developments were consequently not accessible at the time of visit in 1909.

Two veins are exposed on the surface at an elevation of 2,300 feet. They lie in the diorite near the contact of the slates and graywackes of the Berners formation, strike N. 5° E. and dip 70° E. Their trend is therefore nearly at right angles to the contact. The veins are about

50 feet apart; the western one appears to be the larger and in the outcrop is 2 to 3 feet thick, though carrying relatively large horses of diorite. It is a well-defined fissure vein and, as shown by the lower levels, ranges up to 8 feet in thickness.

The main crosscut, which is connected by an aerial tramway 5,000 feet long with the 40-stamp Kensington mill, is 1,900 feet long. It traverses a belt of slates, encountering a number of intruded dikes of diorite porphyry, penetrates the main mass of diorite at 1,500 feet from the portal, and undercuts the ore body at approximately 600 feet below the apex. The foot-wall vein has been stoped out from this level to the surface. Drifts extending north and south have been driven on ten different levels and range in length from 300 to 500 feet. The vein is faulted at the north and its extension has not yet been recovered.

The Comet vein is famous throughout the Juneau district for its pockety character. Masses of golden quartz difficult to break in mining were found, and pockets containing $50,000 or more in value have been extracted, but it is believed that much gold has been lost by "high grading." The total recorded production is $460,000, extracted from 50,000 tons of ore. The ore yielded 87 per cent of its value in free gold and 5 per cent in the concentrates.

JOHNSON MINE.

The Johnson property is situated high up on the side of the amphitheater at the head of Johnson Creek, but is most easily reached by means of a good trail starting from the Sherman Creek side of the divide. The developments consist of a number of shallow surface cuts and a tunnel situated at an altitude of 2,500 feet. The property is located near the contact of the series of amygdaloids with the intrusive diorite, which is coarsely granular and resembles that at the Kensington mine. The amygdaloids have been greatly changed by the effects of the diorite intrusion; they are cut by innumerable dikelets and have been recrystallized, so that they resemble dark finely granular diorites, but they contain numerous small white oval areas representing former amygdules.

The ore body consists of shattered country rock penetrated by quartz stringers, forming a huge stockwork extending up a precipitous gulch from 2,500 feet to the ridge line at an altitude of 3,300 feet, but the upper portion is buried under slide rock. The maximum pyritic mineralization is exposed at the mouth of the tunnel. Here a lenticular mass of fractured and somewhat sheared diorite, 150 feet long and 30 feet wide, forms a compact body of ore in which the quartz stringers are closely spaced and heavily impregnated with pyrite. The trend of the deposit as exposed on the surface is N. 15° W. The tunnel bears N. 69° W. and is 75 feet long. The face is in barren diorite, so that the tunnel is not calculated to develop this portion of the ore body.

The zone of mineralization extends up the gulch as a compact stringer lode 6 to 8 feet thick, broadening out in places so that the individual stringers become widely spaced. At an altitude of 2,800 feet large, irregular bodies of quartz occur and veins and stringers interlace the country rock, including both diorite and greenstone, through a width of 100 feet or more. The quartz here is nearly barren of metallic sulphides, contrasting strikingly in this respect with the large amount shown at the portal of the tunnel. It is reported that commercial sampling shows an ore body 1,500 feet long and from 50 to 70 feet wide, having a minimum average value of $3.90 to the ton.

INDIANA PROPERTY.

The Indiana group, the property of the Alaska Gold Mining Company, is situated on Johnson Creek, three-quarters of a mile northwest of the Jualin mine. It was located in 1896, after the Jualin had been opened, and was acquired by the company in 1897. During the latter year most of the present improvements were made. A 10-stamp mill and accessory buildings were erected and a steel water pipe line several thousand feet in length was laid. The mill has never been operated, and it and the buildings have been demolished by winter snows.

Three tunnels have been driven into the diorite country rock in the attempt to develop the property. The lowermost and main tunnel is 1,100 feet long and trends S. 63° W.; at 1,000 feet from the entrance drifts aggregating 500 feet in length have been driven to the southeast and northwest. They follow a vertical shear zone approximately 10 feet thick, along which the diorite has been reduced to a green schist. Neither quartz veination nor other mineralization appears along this zone. Other belts of schistose diorite (one nearly 100 feet in width) have been crosscut by the main tunnel. They let in large quantities of surface water. A narrow lode of quartz stringers was encountered 60 feet from the mouth, but owing to its proximity to the surface it can not be explored by drifting. The quartz contains considerable pyrite, which is crystallized in large octahedrons, and some chalcopyrite. A second tunnel 100 feet above the lower tunnel is 900 feet long, and the uppermost, 100 feet still higher, is 400 feet long; but neither has encountered any ore.

JUALIN MINE.

The Jualin mine is situated on Johnson Creek at an altitude of 750 feet, and is connected with tidewater at the head of Berners Bay by a horse tramway 4 miles long. Supplies can be lightered at high tide from deep water in Jualin Cove to the wharf at the terminus of the tramway. The mine was located in 1896 by Frank Cook and was purchased in the same year by the Jualin Mines Company, which opened the property and operated the mine continuously until 1901. By that time the larger part of the ore lying above the adit level had been worked out, and deeper development was effected by winzes sunk from drifts on the drainage level. Heavy inflow of surface water impeded the extraction of the ore on the deeper levels, and the mine has been operated only intermittently since 1901. In 1905 the tramway was built to facilitate transportation to the mine. During 1909 the mine was idle, but it is now planned to develop the property systematically. With this end in view it is proposed to sink a shaft during 1910 in the hanging-wall side of the lode.

A 10-stamp mill equipped with Frue vanners and operated by water power is situated on the bank of Johnson Creek below the portal of the working adit of the mine.

The apex of an ore body on the Jualin property was discovered outcropping in a rounded, glacially smoothed knob of diorite projecting through the mat of moss and vegetation that generally obscures all bed rock in the valley of Johnson Creek. The country rock at the Jualin mine is a massive diorite of fairly fine grain and is composed of plagioclase feldspar, small prisms of hornblende, and flakes of biotite. Even in the freshest looking rock many of the feldspars can be seen to have a delicate green tint. In addition to these minerals, which are visible to the eye, the microscope shows that orthoclase and quartz are present in some amount and that therefore the rock approaches a granodiorite in composition. The rock has evidently been permeated by mineral-bearing solutions, and owing to the chemical activity of those waters the primary minerals have suffered considerable alteration. Epidote, chlorite, the scaly green mica sericite, and calcite have been formed at their expense. This alteration is of course most pronounced in proximity to the veins, where in some places a complete transformation of the diorite has occurred, and none of the original minerals have remained intact.

Three parallel veins spaced 75 feet apart on the adit level have been exploited. They trend N. 40° W. and dip steeply to the northeast at angles ranging from 60° to 90°. The foot-wall or west vein, as it is called, has proved to be the most valuable. It has been exposed for 400 feet in length and has averaged 5 feet in width. It has been developed by winzes to a depth of 200 feet below the adit level. At the southeast end of the drift on the adit level the vein has completely pinched out and the diorite at the face is firm and massive; before pinching, the dip is abruptly reversed to a flatter angle and the vein apparently loses itself in a zone of crushed diorite. About 50 feet to the northwest along the trend the vein is 16 to 24 inches thick and the hanging wall is splendidly defined, dipping steeply to the northeast; the foot-wall is marked by a closely foliated green schist produced by the mashing of the diorite. That this crushing took place prior to the filling of the vein is proved by the fact that the quartz near the foot-wall incloses fragments of the schist. From this point the vein abruptly expands to 10 feet in width. Part of this increased thickness seems to be due to movement along a fault plane traversing the vein at a narrow angle with the trend of the vein. Faults of small displacement have been encountered at other points in the mine, but have occasioned no difficulties in the exploitation of the ore bodies.

The middle vein as exposed in the main adit shows well-defined walls, which break clean, but the vein is only 18 inches thick at this point and consists of quartz and partly replaced diorite. The dip is rather flat—30° N. More or less shattered country rock adjoins the vein and is penetrated by sporadic stringers of quartz. The next 120 feet of the adit is driven on a shear zone of irregular width ranging from 4 to 8 feet; quartz is present only as stringers. The dip of the ore body gradually steepens, and at 120 feet a large body of quartz was encountered which averaged 10 feet in width throughout its length of 400 feet. This vein has yielded several thousand tons of ore in past years, but its value is said to be too low to warrant further extraction.

The third or hanging-wall vein is 4 to 5 feet thick and is of somewhat better grade than the second ore body. It is characterized by a clean, well-defined hanging wall, but the foot-wall is less regular and is reticulated by a considerable number of quartz veinlets, which are accompanied by an impregnation of the diorite with cubical pyrite.

The quartz of the veins is of milk-white color and open texture and is characterized by the presence of numerous druses or small vugs, into which terminated quartz crystals project. Metallic sulphides are present in considerable abundance and consist mainly of pyrite, chalcopyrite, and galena. Black sphalerite occurs also, but is extremely rare. Free gold is not uncommon and seems to be associated particularly with the chalcopyrite, in which it is usually embedded. The ore and wall rock show to some extent the oxidizing effect of surface waters, as indicated by the presence of red iron ocher and of malachite and azurite, though the copper carbonates are comparatively rare. Free gold can be found here and there in the midst of small masses of iron oxide, where it has undoubtedly been freed by the oxidation of the pyritic mineral that originally inclosed it.

The oxidation affecting the upper parts of the lodes is of postglacial origin and is comparatively feeble. The products of any earlier oxidation and enrichment of the outcrops of the lodes have been swept away by the powerful glacial erosion to which the region was subjected. These facts—the lack of oxidation and the glacial erosion—make it probable that the distribution of the gold in the veins has undergone only slight rearrangement from the action of descending solutions and that therefore the tenor of the ore is not likely to decrease with depth.

FREMMING PROPERTY.

The Fremming property is situated on Johnson Creek about a mile below the Jualin mine. The valley floor at this point is mantled by several feet of gravel and black soil covered with sod. Stripping shows that the bed rock is glacially polished and striated. Near the blacksmith shop an intrusion contact of the Jualin diorite with a series of green schists is exposed. Small dikes of diorite penetrate the schist, which, if the relations were not clearly shown, might be regarded as a chloritic schist produced by dynamic metamorphism of the diorite itself. Both the diorite and the green schist are interlaced with irregular quartz stringers.

A shaft 85 feet deep has been sunk near the contact in the green schists. The main development consists of a crosscut tunnel 360 feet long, commencing on the east bank of Johnson Creek and trending N. 28° E. A short drift connects the crosscut tunnel with the bottom of the shaft. The tunnel crosscuts a nearly vertical series of green schists. These are derived from slates and graywacke-slates of the Berners formation and owe their stronger green color to a greater abundance of chlorite in them. Near the end of the crosscut a belt of schists is irregularly penetrated by stringers across a width of 6 feet. The veinlets and partly replaced chloritic rock consist of quartz and calcite containing pyrite, chalcopyrite, galena, resinous sphalerite, and free gold. Rich specimen ore can be obtained, but the present developments are inadequate to show whether a body of milling ore exists.

GREEK BOY PROPERTY.

The Greek Boy property is situated 4 miles north of the tidewater terminus of the Jualin tramway and half a mile from Berners River. It is the lowest lying property in the region, the principal workings being only 100 feet above sea level.

The main development consists of a tunnel nearly 700 feet long, trending northwest. For the first few hundred feet it makes a narrow angle with the strike of the lode; the last 300 feet is driven on the lode. The ore body follows the contact of the quartz diorite gneiss with the basalts, which are here thoroughly schistose, and is a strong stringer lode bounded by definite walls. It stands nearly vertical, dipping steeply to the south. The hanging wall is a black hornblende schist, which the microscope shows to be composed mainly of hornblende and some plagioclase.

The first rock encountered on entering the tunnel is a gneissic or schistose diorite consisting of numerous white rounded feldspars embedded in a black matrix made up of hornblende and biotite. With increasing proximity to the lode this rock becomes finer grained and nearly barren of dark minerals. As the lode lies along the contact of an intruded formation, this change means that the rock is a marginal phase of the diorite, a change noted in other parts of the field where it is not obscured, as it is here, by the subsequent alterations produced by vein-forming solutions.

The lode consists of the schistose marginal phase of the diorite reticulated with quartz stringers, forming in places an ore body of nearly solid quartz. At other places considerable country rock is included in the lode. The thickness ranges from 4 to 9 feet and averages perhaps 7 feet. The only metallic mineral noted in the quartz is pyrite, and this is present in sparse amount only.

RECENT SURVEY PUBLICATIONS ON ALASKA.

[Arranged geographically. A complete list can be had on application.]

All these publications can be obtained or consulted in the following ways:

1. A limited number are delivered to the Director of the Survey, from whom they can be obtained free of charge (except certain maps) on application.

2. A certain number are delivered to Senators and Representatives in Congress for distribution.

3. Other copies are deposited with the Superintendent of Documents, Washington, D. C., from whom they can be had at prices slightly above cost. The publications marked with an asterisk (*) in this list are out of stock at the Survey, but can be purchased from the Superintendent of Documents at the prices stated.

4. Copies of all government publications are furnished to the principal public libraries throughout the United States, where they can be consulted by those interested.

GENERAL.

*The geography and geology of Alaska, a summary of existing knowledge, by A. H. Brooks, with a section on climate, by Cleveland Abbe, jr., and a topographic map and description thereof, by R. U. Goode. Professional Paper 45, 1906, 327 pp. $1.

Placer mining in Alaska in 1904, by A. H. Brooks. In Bulletin 259, 1905, pp. 18-31.

The mining industry in 1905, by A. H. Brooks. In Bulletin 284, 1906, pp. 4-9.

The mining industry in 1906, by A. H. Brooks. In Bulletin 314, 1907, pp. 19-39.

*The mining industry in 1907, by A. H. Brooks. In Bulletin 345, pp. 30-53. 45 cents.

The mining industry in 1908, by A. H. Brooks. In Bulletin 379, 1909, pp. 21-62.

The mining industry in 1909, by A. H. Brooks. In Bulletin 442, 1910, pp. 20-46.

Railway routes, by A. H. Brooks. In Bulletin 284, 1906, pp. 10-17.

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The preparation and use of peat as a fuel, by C. A. Davis. In Bulletin 442, 1910, pp. 101-132.

*The distribution of mineral resources in Alaska, by A. H. Brooks. In Bulletin 345, pp. 18-29. 45 cents.

Mineral resources of Alaska, by A. H. Brooks. In Bulletin 394, 1909, pp. 172-207.

*Methods and costs of gravel and placer mining in Alaska, by C. W. Purington. Bulletin 263, 1905, 362 pp. 35 cents. Abstract in Bulletin 259, 1905, pp. 32-46.

*Prospecting and mining gold placers in Alaska, by J. P. Hutchins. In Bulletin 345, 1908, pp. 54-77. 45 cents.

Geographic dictionary of Alaska, by Marcus Baker; second edition by James McCormick. Bulletin 299, 1906, 690 pp.

*Water-supply investigations in Alaska in 1906-7, by F. F. Henshaw and C. C. Covert. Water-Supply Paper 218, 1908, 156 pp. 25 cents.

Topographic maps.

Alaska, topographic map of; scale, 1 : 2,500,000; preliminary edition; by R. U. Goode. Contained in Professional Paper 45. Not published separately.
Map of Alaska showing distribution of mineral resources; scale, 1 : 5,000,000; by A. H. Brooks. Contained in Bulletin 345 (in pocket).
Map of Alaska; scale, 1 : 5,000,000; by Alfred H. Brooks.

SOUTHEASTERN ALASKA.

*Preliminary report on the Ketchikan mining district, Alaska, with an introductory sketch of the geology of southeastern Alaska, by Alfred H. Brooks. Professional Paper 1, 1902, 120 pp. 25 cents.
*The Porcupine placer district, Alaska, by C. W. Wright. Bulletin 236, 1904, 35 pp. 15 cents.
The Treadwell ore deposits, by A. C. Spencer. In Bulletin 259, 1905, pp. 69-87.
Economic developments in southeastern Alaska, by F. E. and C. W. Wright. In Bulletin 259, 1905, pp. 47-68.
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*Copper deposits on Kasaan Peninsula, Prince of Wales Island, by C. W. Wright and Sidney Paige. In Bulletin 345, 1908, pp. 98-115. 45 cents.
The Ketchikan and Wrangell mining districts, Alaska, by F. E. and C. W. Wright. Bulletin 347, 1908, 210 pp.
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CONTROLLER BAY, PRINCE WILLIAM SOUND, AND COPPER RIVER REGIONS.

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Coal resources of southwestern Alaska, by R. W. Stone. In Bulletin 259, 1905, pp. 151–171.

Gold placers of Turnagain Arm, Cook Inlet, by F. H. Moffit. In Bulletin 259, 1905, pp. 90-99.

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The Yukon-Tanana region, Alaska; description of the Fairbanks and Rampart quadrangles, by L. M. Prindle, F. L. Hess, and C. C. Covert. Bulletin 337, 1908, 102 pp.

*Occurrence of gold in the Yukon-Tanana region, by L. M. Prindle. In Bulletin 345, 1908, pp. 179–186. 45 cents.

*The Fortymile gold-placer district, by L. M. Prindle. In Bulletin 345, 1908, pp. 187–197. 45 cents.

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The Koyukuk-Chandalar gold region, by A. G. Maddren. In Bulletin 442, 1910, pp. 284–315.

Topographic maps.

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The Fairbanks quadrangle; scale, 1:250,000; by T. G. Gerdine, D. C. Witherspoon, and R. B. Oliver. For sale at 10 cents a copy or $6 per hundred.

Rampart quadrangle; scale, 1:250,000; by D. C. Witherspoon and R. B. Oliver. For sale at 10 cents a copy or $6 per hundred.

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*Investigation of the mineral deposits of Seward Peninsula, by P. S. Smith. In Bulletin 345, 1908, pp. 206–250. 45 cents.
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Geology of the Seward Peninsula tin deposits, by Adolph Knopf. Bulletin 358, 1908, 72 pp.
Recent developments in southern Seward Peninsula, by P. S. Smith. In Bulletin 379, 1909, pp. 267–301.
The Iron Creek region, by P. S. Smith. In Bulletin 379, 1909, pp. 302–354.
Mining in the Fairhaven precinct, by F. F. Henshaw. In Bulletin 379, 1909, pp. 355–369.
Water-supply investigations in Seward Peninsula in 1908, by F. F. Henshaw. In Bulletin 379, 1909, pp. 370–401.
Geology and mineral resources of the Solomon and Casadepaga quadrangles, Seward Peninsula, by P. S. Smith. Bulletin 433, 1910, 227 pp.
Mineral resources of the Nulato-Council region, by P. S. Smith and H. M. Eakin. In Bulletin 442, 1910, pp. 316–352.
Mining in Seward Peninsula, by F. F. Henshaw. In Bulletin 442, 1910, pp. 353–371.
Water-supply investigations in Seward Peninsula in 1909, by F. F. Henshaw. In Bulletin 442, 1910, pp. 372–418.

Topographic maps.

The following maps are for sale at 5 cents a copy or $3 per hundred:

Casadepaga quadrangle, Seward Peninsula; scale, 1:62,500; by T. G. Gerdine.
Grand Central special, Seward Peninsula; scale, 1:62,500; by T. G. Gerdine.
Nome special, Seward Peninsula; scale, 1:62,500; by T. G. Gerdine.
Solomon quadrangle, Seward Peninsula; scale, 1:62,500; by T. G. Gerdine.

The following maps are for sale at 25 cents a copy or $15 per hundred:

Seward Peninsula, northeastern portion of, topographic reconnaissance of; scale, 1:250,000; by T. G. Gerdine.
Seward Peninsula, northwestern portion of, topographic reconnaissance of; scale, 1:250,000; by T. G. Gerdine.
Seward Peninsula, southern portion of, topographic reconnaissance of; scale, 1:250,000; by T. G. Gerdine.

In press.

A geologic reconnaissance in southeastern Seward Peninsula and the Norton Bay-Nulato region, by P. S. Smith and H. M. Eakin. Bulletin 449.

In preparation.

Geology of the area represented on the Nome and Grand Central special maps, by F. H. Moffit, F. L. Hess, and P. S. Smith.

The water resources of the Seward Peninsula, by F. F. Henshaw.

NORTHERN ALASKA.

A reconnaissance from Fort Hamlin to Kotzebue Sound, Alaska, by way of Dall, Kanuti, Allen, and Kowak rivers, by W. C. Mendenhall. Professional Paper 10, 1902, 68 pp.

*A reconnaissance in northern Alaska across the Rocky Mountains, along the Koyukuk, John, Anaktuvuk, and Colville rivers, and the Arctic coast to Cape Lisburne, in 1901, by F. C. Schrader and W. J. Peters. Professional Paper 20, 1904, 139 pp.

Coal fields of the Cape Lisburne region, by A. J. Collier. In Bulletin 259, 1905, pp. 172-185.

Geology and coal resources of Cape Lisburne region, Alaska, by A. J. Collier. Bulletin 278, 1906, 54 pp.

Topographic maps.

Fort Yukon to Kotzebue Sound, reconnaissance map of; scale, 1: 1,200,000; by D. L. Reaburn. Contained in Professional Paper 10. Not published separately.

*Koyukuk River to mouth of Colville River, including John River; scale, 1: 1,200,000; by W. J. Peters. Contained in Professional Paper 20. Not published separately.

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DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, DIRECTOR

BULLETIN 447

MINERAL RESOURCES

OF

JOHNSTOWN, PENNSYLVANIA AND VICINITY

BY

W. C. PHALEN

AND

LAWRENCE MARTIN

SURVEYED IN COOPERATION WITH THE
TOPOGRAPHIC AND GEOLOGIC SURVEY COMMISSION OF PENNSYLVANIA

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MINERAL RESOURCES OF JOHNSTOWN, PENNSYLVANIA, AND VICINITY.

By W. C. PHALEN and LAWRENCE MARTIN.

INTRODUCTION.

This report is one of a number of bulletins and geologic folios containing the results of geologic investigations carried on by the United States Geological Survey in cooperation with the Topographic and Geologic Survey Commission of Pennsylvania. Several papers based on this work, for which the State paid one-half the cost, have been or will soon be published by the State; others are in preparation for publication by the United States Geological Survey.

The field work on which this bulletin is based was done in the summer of 1906 by W. C. Phalen, assisted by Lawrence Martin. George H. Ashley, under whose supervision the work was done, visited the field and went over some of the more critical points.

GEOGRAPHY.

Location.—The Johnstown quadrangle is situated in southwest-central Pennsylvania, mostly in Cambria County, but extending also over small parts of Somerset, Westmoreland, and Indiana counties. (See Pl. I, pocket.) Its area is about 228 square miles. It lies near the eastern edge of the Allegheny Plateau province and near the northeastern edge of the great bituminous coal field that extends from the southern part of New York to northern Alabama; its position in this field is shown in Plate II.

Commercial geography.—This quadrangle lies in the plateau region west of the Allegheny Front. Its most important streams are Conemaugh River (formed by the union of Stony Creek and Little Conemaugh River at Johnstown), Blacklick Creek and its South Branch, and South Fork of Conemaugh River. Conemaugh River has long afforded one of the most available highways of communication across the region from the coast to the Middle West; the first railroad (the old Portage and Canal route) and the main line of the Pennsylvania Railroad have both used this valley. The development of the iron resources of the region was thus early stimulated, and in turn an impetus was given to the development of the coal resources, until at the present time Johnstown and the neighboring towns are among the leading coal and iron centers of western Pennsylvania.

Stony Creek flows northward, in its course forming part of the boundary between Somerset and Cambria counties, this part of its course lying entirely within the Johnstown Basin. The South Fork of Conemaugh River heads near the summit of Allegheny Mountain, near the Cambria-Bedford county line in the Ebensburg quadrangle, which adjoins the Johnstown quadrangle on the east. South and North branches of Blacklick Creek join near Vintondale and the main stream continues westward along the northern edge of the area. In a general way the drainage of the quadrangle flows from east to west. The main structural and to a less noticeable extent the main topographic features trend northeast and southwest. The drainage and structure thus intersect at a fairly large angle—a condition which has proved of vast economic importance, for it has resulted in the cutting of deep valleys and the exposing of valuable clay and coal beds. Moreover, it has made possible the exploitation on a large scale of the mineral wealth by drifting along the outcrop—a much safer and cheaper method than shafting and one tending to the most rapid development of a coal region. The streams have determined the location of the local railway systems and have made their construction fairly easy.

TOPOGRAPHY.

RELIEF.

The form of the surface of the Johnstown quadrangle bears a close and striking relation to the geology and structure. The highest points in the area are along the crest of Laurel Ridge, which south of Conemaugh River is more than 2,700 feet high at a few points. Laurel Ridge is a structural feature—that is, it is dependent on the character of the rocks brought to the surface by the structure. These are largely the sandstones of the Pocono and Pottsville formations. Where rocks of this character cover the surface the country is wild and surface cultivation is out of the question. Farther north along the ridge the sandy sediments dip below drainage level and the rocks of the Allegheny formation ("Lower Productive Coal Measures") and the Conemaugh formation ("Lower Barren Coal Measures") appear in the hills, as, for instance, along South Branch of Blacklick Creek. The changes in vegetation and general conditions accompanying the gradual disappearance of the sandy beds below the surface are noticeable north of South Branch of Blacklick Creek, and in this region the country is almost all under cultivation.

In the southeast corner of the quadrangle the highest hills are a little more than 2,700 feet high. Here also the beds are involved in the structural uplift along the front of Allegheny Mountain, and the rocks along the crest of the mountain are chiefly the same sandstones as occur on Laurel Ridge.

The lowest points in the area are on Conemaugh River, at the western edge of the quadrangle. At Conemaugh Furnace station the elevation is 1,134.54 feet. The extremes in the topography are well brought out near by, for Conemaugh River in descending from 1,185 feet at Johnstown to 1,135 feet at Conemaugh Furnace flows through a gorge the hills on either side of which rise 1,600 feet higher.

The greater portion of the area has an elevation between the extremes given above. In detail the surface is decidedly hilly, but most of the hill slopes are rather gentle, especially back from the main drainage channels. The badly dissected character of the ridge has, however, an important bearing on the availability and exploitation of the natural resources of the region. There is very little level land in the quadrangle, what there is being confined almost solely to the lower stretches of Blacklick Creek in Indiana County.

Points of equal elevation are represented on the contour map by light-brown lines, which really represent the intersections of hypothetical horizontal planes with the surface of the country. They are placed 20 feet apart and indicate the "lay of the land" with great precision.

SURVEYS.

TRIANGULATION STATIONS.

The topographic work for the map of the Johnstown quadrangle (Pl. I) is based on triangulation stations established by the United States Geological Survey within the boundaries of the quadrangle or comparatively near its borders to the east and north. (See fig. 1.) Descriptions of the exact locations of these triangulation stations are given below:

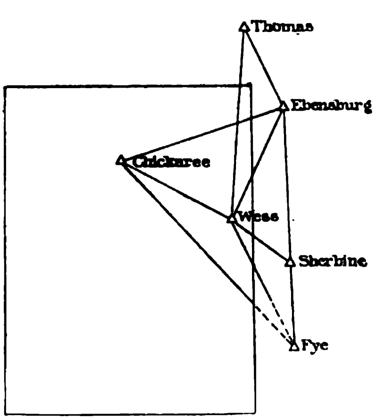

FIGURE 1.—Sketch map showing location of triangulation stations on which survey of Johnstown quadrangle is based.

CHICKAREE, CAMBRIA COUNTY.

On a cleared knob in the central part of Jackson Township, 10 miles by road westward from Ebensburg, 300 yards south of the Chickaree Hill schoolhouse.

Station mark: A marble post 34 by 6 by 6 inches set 32 inches in the ground, in the center of top of which is countersunk and cemented a bronze triangulation tablet.

[Latitude 40° 26′ 38.97″. Longitude 78° 52′ 48.29″.]

To station—	Azimuth.			Back azimuth.			Log. distance.
	°	′	″	°	′	″	*Meters.*
Ebensburg	251	24	48.82	71	30	51.47	4.1425539
Wess	292	00	35.81	112	04	41.22	3.9833693
Fye	318	31	18.78	138	37	47.50	4.3303852

EBENSBURG, CAMBRIA COUNTY.

Station is center of cupola of courthouse in Ebensburg.
Station mark: Center of cupola.

[Latitude 40° 29′ 02.07″. Longitude 78° 43′ 29.50″.]

To station—	Azimuth.			Back azimuth.			Log. distance.
	°	′	″	°	′	″	*Meters.*
Thomas	156	58	25.25	336	57	06.21	3.8644894
Carrolltown	185	49	38.40	5	50	15.62	4.1222362
Wopsononock	248	52	46.94	69	03	52.34	4.4120176
Tunnel Hill	270	56	22.25	91	03	22.64	4.1833793
Sherbine	0	52	21.75	180	52	15.82	4.1515885
Wess	27	55	04.38	207	53	07.38	3.9581867
Chickaree	71	30	51.47	251	24	48.82	4.1425539

WESS, CAMBRIA COUNTY.

In the northern portion of Croyle Township, 8 miles southwest of Ebensburg, 1 mile west of New Germany, in a pasture owned by Leo Wess. Theodolite elevated 35 feet.

Station mark: A marble post 36 by 6 by 6 inches set 32 inches in the ground, in the center of the top of which is countersunk and cemented a bronze triangulation tablet.

Reference mark: Line fence due north 44 feet distant. Center of big dead tree, N. 65° W. (magnetic), 31 feet distant.

[Latitude 40° 24′ 41.86″. Longitude 78° 46′ 29.85″.]

To station—	Azimuth.			Back azimuth.			Log. distance.
	°	′	″	°	′	″	*Meters.*
Chickaree	112	04	41.22	292	00	35.81	3.9833693
Thomas	185	20	37.23	5	21	15.32	4.1710473
Ebensburg	207	53	07.38	27	55	04.38	3.9581867
Sherbine	326	41	29.11	146	43	20.03	3.8666773
Fye	337	09	43.27	157	12	06.81	4.1299536

SHERBINE, CAMBRIA COUNTY.

On a small hill having scattering locust trees on its summit, in Croyle Township, about one-fourth mile west of the Summerhill Township line, 2 miles southwest of Wilmore, 2 miles southeast of Summerhill post-office, on land of Aaron Sherbine. Theodolite elevated 28 feet.

Station mark: A marble post 36 by 6 by 6 inches set 32 inches in the ground, in the center of top of which is countersunk and cemented a bronze triangulation tablet.

[Latitude 40° 21′ 22.50″. Longitude 78° 43′ 38.65″.]

To station—	Azimuth.	Back azimuth.	Log. distance.
	° ′ ″	° ′ ″	*Meters.*
Wess	146 43 20.03	326 41 29.11	3.8666773
Ebensburg	180 52 15.82	0 52 21.75	4.1515885
Tunnel Hill	228 00 07.85	48 07 13.50	4.3183273
Fye	349 15 37.33	169 16 09.98	3.8058254

FYE, CAMBRIA COUNTY.

[Not occupied.]

A cleared ridge known as the Fye place, owned by the Mountain Coal Company, in Adams Township, 6 miles south of Summerhill and 7 miles southeast of South Fork.

Station mark: A marble post 36 by 6 by 6 inches set 32 inches in the ground, in the center of top of which is countersunk and cemented a bronze triangulation tablet.

Reference mark: The lone locust signal tree 4 feet north of station mark.

[Latitude 40° 17′ 58.79″. Longitude 78° 42′ 48.19″.]

To station—	Azimuth.	Back azimuth.	Log. distance.
	° ′ ″	° ′ ″	*Meters.*
Chickaree	138 37 47.50	318 31 18.78	4.3303852
Wess	157 12 06.81	337 09 43.27	4.1299536
Sherbine	169 16 09.98	349 15 37.33	3.8058254

SPIRIT LEVELING.

The topography of the Johnstown quadrangle is shown on Plate I by buff-colored contour lines based on precise levels run by the United States Geological Survey. In running these levels numerous bench marks were established, their elevations being based on an aluminum tablet in the foundation of the Seventh Avenue Hotel, Pittsburg, Pa., marked "738 Pittsburg, 1899," the elevation of which is now accepted as 738.384 feet above mean sea level. The initial points on which these levels depend are various bench marks along the precise-level lines of the Pennsylvania Railroad, the accepted heights having been determined by the 1903 adjustment.

The work on the Johnstown quadrangle was done by Mr. George Seidel, levelman, in 1902.

The descriptions and elevations of these bench marks are given below:

Johnstown south along Baltimore and Ohio Railroad to Ingleside.

	Feet.
Johnstown, at west end of north parapet of railroad bridge; copper bolt (Pennsylvania Railroad bench mark)	1,180.27
Johnstown, east end of south parapet of Pennsylvania Railroad bridge; aluminum tablet stamped "1180 PITTS"	1,180.261
Johnstown, railroad ticket office, on window sill; chiseled shelf (Pennsylvania Railroad bench mark)	1,187.60
Johnstown, road crossing at Pennsylvania Railroad station; top of rail	1,184
Johnstown, in front of Baltimore and Ohio Railroad station; top of rail	1,169
Stony Creek, road crossing at station; top of rail	1,194
Johnstown, 3 miles south of, Baltimore and Ohio Railroad and trolley grade crossing; top of rail	1,191
Kring, road crossing at station; top of rail	1,241
Ingleside, 700 feet north of, northeast corner of small railroad bridge; copper bolt marked "1275 PITTS"	1,275.610

Ingleside northeast along Pennsylvania Railroad via Elkton to Salix.

Scalp Level, 0.45 mile north of, west side of track, 75 feet west of tool house, in large sandstone; aluminum tablet stamped "1719 PITTS"	1,719.225
Salix, 870 feet north of station, under Pennsylvania Railroad culvert, west wall; bronze tablet stamped "2050 PITTS"	2,049.455
Salix, railroad bridge at station, north parapet, east end; aluminum tablet stamped "2077 PITTS"	2,077.762

Seward northeast along Pennsylvania Railroad via Vintondale and Nanty Glo to Ebensburg.

Seward, 0.17 mile west of V. K. tower, railroad bridge No. 226 over Piney Run, north parapet, east end of arch; copper bolt (Pennsylvania Railroad bench mark)	1,091.571
Seward, doorstep of waiting room of station; copper bolt marked "1122 U. S."	1,122.145
Seward, crossing at station; top of rail	1,120
Wehrum, crossing at station; top of rail	1,360
Vintondale, 150 feet east of station, iron bridge, south end of west abutment; aluminum tablet stamped "1403 PITTS"	1,402.741
Twin Rocks, crossing at station; top of high rail	1,668
Nanty Glo, 200 feet south of station, iron bridge, west end of north abutment; bronze tablet stamped "1706 PITTS"	1,705.761
Nanty Glo, crossing at station; top of high rail	1,710
Beulah Road, in front of station; top of rail	1,894

STRATIGRAPHY.

GENERAL STATEMENT.

The surface rocks in the Johnstown quadrangle are entirely of sedimentary origin, all of them having been deposited in or by water. They consist of sandstones, shales, limestones, and coal and iron-ore beds, the whole having a thickness of approximately 3,100 to 3,200 feet. These rocks belong in the Devonian and Carboniferous systems, except for the imperfectly consolidated gravels of the river terraces, which are tentatively regarded as of Pleistocene age, and the recent alluvium of the flood plains. The Carboniferous rocks are of chief importance, as they contain the workable coals and clays. All these rocks will be described in descending order, beginning with the youngest.

QUATERNARY SYSTEM.

RECENT RIVER DEPOSITS (ALLUVIUM).

The alluvium of the streams of this area is the youngest bedded deposit. It consists of fine material, chiefly sand and clay, laid down by the present streams during periods of high water, and is present in varying amounts along most of the streams, though occupying as a rule small areas only. The most important alluvial area is that at the confluence of Conemaugh River and Stony Creek, on which the greater part of the city of Johnstown and its suburbs is located. Other important areas of alluvium are found on Blacklick Creek near the northwestern corner of the quadrangle. All the level land in this part of the quadrangle is under cultivation.

PLEISTOCENE DEPOSITS.

Along Conemaugh River and Stony Creek occur deposits which can not be correlated strictly with the alluvium or recent flood-plain deposits. This material, which consists of rounded bowlders varying up to 2 or 3 feet in greatest dimension, mingled with sand and clay in small quantities, is found at two or more distinct horizons. The lower deposit is well developed along the main line of the Pennsylvania Railroad and is shown in small cuts a short distance east of Mineral Point. On the Baltimore and Ohio Railroad a short distance south of the quadrangle, north of the mouth of Paint Creek, near Kring, and near the suburb of Roxbury are also excellent exposures. At the quarry of B. H. Campbell, north of Sheridan, rounded bowlders occur 100 feet above the level of the Pennsylvania Railroad. This deposit is similar in all respects to the lower one occurring along Stony Creek. These bowlders show in the foreground of Plate V, *B* (p. 28). The material is considered to be Pleistocene in age. It has no economic importance.

CARBONIFEROUS SYSTEM.

PENNSYLVANIAN SERIES.

CONEMAUGH FORMATION.

GENERAL CHARACTER.

The Conemaugh formation includes the rocks lying below the Pittsburg coal and above the Upper Freeport coal. A nearly complete section of these rocks was obtained from drill records and by hand-level work along the Pennsylvania Railroad in the deepest part of the Wilmore structural basin. The upper 200 feet or so of the section represents barometric work along the roads in the Ebensburg quadrangle to the east. It has been thought advisable to give the section of the Conemaugh thus obtained in this locality as a matter of record, but it will be understood that such a detailed section necessarily is constant over a very small area. Some of the sandstones, for instance, die out completely within a short distance and other lentils appear in the section either slightly higher up or lower down. In general, local names are applied to such sandstone lentils where their position is known to be fairly well defined in the geologic column.

The section of the Conemaugh formation is as follows:

Section of the Conemaugh formation in the Wilmore Basin.[a]

	Thickness.		Total.	
	Ft.	*in.*	*Ft.*	*in.*
Sandstones and sandy shale layers with intercalated limestones	200		200	
Shale	20		220	
Sandstone (Wilmore)	17		237	
Shale	5		242	
Limestone, sandy	2		244	
Shale, green, weathering to clay	23		267	
Shale, dark drab	15		282	
Sandstone, containing a 10 to 12 inch limestone layer and with a possible coal bloom	6		288	
Shale	10		298	
Limestone	9		307	
Shale, green	6		313	
Limestone	1		314	
Shale, concretionary	2		316	
Fire clay	1		317	
Shale, concretionary	4		321	
Shale, olive	1		322	
Shale, dark	10		332	
Sandstone	1		333	
Shale, blue-black	3		336	
Limestone	3		339	
Shale	20		359	
Sandstone (Summerhill)	45		404	
Shale, with sandy and limestone layers	30		434	
Sandstone, shaly	25		459	
Shale, dark blue, weathering like sandstone	25		484	
Sandstone	2		486	
Limestone	3		489	
Limestone grading into sandstone	6		495	
Morgantown ("Ebensburg") sandstone member: Sandstone, hard, gray	25		520	
Morgantown ("Ebensburg") sandstone member: Shale		3½	520	3½
Morgantown ("Ebensburg") sandstone member: Sandstone, hard, gray	7	5½	527	9
Shale, sandy	3	2	530	11
Sandstone	5	1	536	

[a] First 200 feet, barometric measurements along roads; section hand-leveled from 200 to 495 feet; below 495 feet record obtained from a bore hole on the Pennsylvania Railroad opposite the signal tower between Wilmore and Summerhill.

Section of the Conemaugh formation in the Wilmore Basin—Continued.

	Thickness.		Total.	
	Ft.	*in.*	*Ft.*	*in.*
Shale	9	2½	545	2½
Coal (called 600-foot rider owing to its position at about 600 feet above the Lower Kittanning or B coal)		10	546	½
Shale	29	2	575	2½
Shale, red	6	1	581	3½
Shale	7	7	588	10½
Sandstone and shale	18	4	607	2½
Shale, calcareous	6	8	613	10½
Shale with calcareous and clay streaks	13	2	627	½
Shale, sandy	8	10	635	10½
Shale	3	5	639	3½
Shale, calcareous	6	10½	646	2
Shale, sandy	7	10	654	
Sandstone	31	2½	685	2½
Shale, with bony streaks		8	685	10½
Sandstone	15	5½	701	4
Shale	4	10½	706	2½
Shale, sandy } Buffalo sandstone member	19		725	2½
Sandstone } Buffalo sandstone member	28	1	753	3½
Slate and sandstone } Buffalo sandstone member	12	3	765	6½
Sandstone with congomerlate layers	55	2½	820	9
Slate	4	3	825	
Slate, sandy	7	6	832	6
Slate	28	6½	861	½
Slate, sandy	7	6½	868	7
Shale		11½	869	6½
Slate, sandy	4	6	874	½
Slate	11	7½	885	8
Sandstone	3	4	889	
Shale	10	3	899	3
Shale, red	4	11	904	2
Sandstone	10	3	914	5
Shale	8	3	922	8
Sandstone	2	8½	925	4½
Shale with sandstone layers	21	6	946	10½
Sandstone		11½	947	10
Slate	1	3	949	1
Sandstone	10	1	959	2
Slate	5		964	2
Top of Upper Freeport coal.				

With this section may be compared the following section of a part of the Conemaugh, measured by John Fulton, in Prossers Knob, near Johnstown:[a]

Section of part of the Conemaugh formation in Prossers Knob, near Johnstown.

	Ft.	In.
Stone quarry; sandstone	20	
Shales, olive	17	
Shales, drab	18	
Sandstone, thin bedded	10	
Shales	8	
Iron ore, siliceous	3	
Shales, olive and drab	68	
Shales, red	10	
Shales, olive	12	
Slate and sandstone	10	
Sandstone, white	26	
Shales, drab	13	
Sandstone, massive, drab, forming cliff	20	
Coal		3

[a] Second Geol. Survey Pennsylvania, Rept. H2, p. 97.

		Ft.	in.
Shale, drab		4	
Sandstone, drab		7	
Slates		2	
Johnstown iron-ore seam		2	
Shales, flesh and drab colored	Place of the Mahoning sandstone.	13	
Shales, iron stained		9	
Iron ore			10
Fire clay		2	
Shales, soft, drab		8	
Fire clay and shales		4	
Shales, drab, and sandstone		15	
Coal, Upper Freeport or E		3	

According to the section (pp. 16–17), the Conemaugh is nearly 1,000 feet thick, this estimate, however, being subject to the question of the correct correlation of the Pittsburg coal. It is made up essentially of shales and sandstones, with a few beds of limestone. Streaks of coal are present here and there, but only locally are they of sufficient thickness and purity to be worked even in a small way. Fire clay, both plastic and flint, occurs in the formation in certain parts of the area. A bed of iron ore described in the reports of the Second Geological Survey of Pennsylvania as the Johnstown ore has been found on Mill Creek, north and west of Johnstown, and near the position of the old Cambria furnace at the base of Laurel Hill; it lies 50 feet above the Upper Freeport coal. Considerable historical importance attaches to this ore body, for its presence determined the beginning of the iron industry near Johnstown and undoubtedly influenced the present vigorous development of the coal.

DETAILED DESCRIPTION.

The higher portion of the Conemaugh in the Johnstown quadrangle is made up of sandstones and shales, with occasional beds of limestone. As it has been found difficult to correlate these sandstones with the typical members in the Pittsburg district and Allegheny Valley, they are here referred to by the local names given them in the Ebensburg quadrangle, which lies immediately east of the area under discussion.

Wilmore sandstone member.—The highest of these sandstones was called by Butts [a] the Wilmore sandstone. It shows in the top of the first railway cut west of Wilmore and in the neighboring hills. Its position with reference to the Upper Freeport coal is indicated in the section on pages 16–17. It is usually not more than 20 feet thick.

Summerhill sandstone member.—Next comes the Summerhill sandstone member, whose base lies 560 feet above the Upper Freeport coal. It varies from 30 to 45 feet in thickness. It was named by

[a] Ebensburg folio (No. 133), Geol. Atlas U. S., U. S. Geol. Survey, 1905, p. 5.

Butts from the village of Summerhill, in the eastern part of the Johnstown quadrangle. It outcrops conspicuously in all the hills between Wilmore and Summerhill, especially in a bluff east of the latter town. It is as a rule decidedly laminated in appearance, differing in this respect from the massive Morgantown ("Ebensburg") sandstone below.

Morgantown ("Ebensburg") sandstone member.—The next lower stratum of note in this area is a sandstone which Butts called the Ebensburg, but which in this report will be termed the Morgantown sandstone member. This sandstone lies between 400 and 450 feet above the Upper Freeport coal in the southeastern part of the quadrangle and probably less than 400 feet above it in the northern part. It is excellently developed near Elton in the Johnstown area.

Harlem (?) coal.—The Morgantown sandstone is closely underlain by a thin coal known as the 600-foot rider, as it is usually 600 feet above the Lower Kittanning coal. It outcrops near the old dam site on South Fork of Conemaugh River (Pl. III, *A*). It is possible that this corresponds to the Harlem or Friendsville coal, but this correlation is provisional, as it is hazardous to attempt close correlation with the upper portions of the Conemaugh in the western part of the State.

Red shale.—The next lower stratum persistent enough to be traced with certainty is a band of red shales 30 feet or less in thickness. These occur in nearly all parts of the quadrangle, though the distance of their top above the Upper Freeport coal is not constant, varying from 300 to 400 feet. They may correspond to the red shale in the western part of the State, to which I. C. White has given the name Pittsburg red shales.

Saltsburg sandstone member.—Around Johnstown the top of what is regarded as the representative of the Saltsburg sandstone member lies about 300 feet above the Upper Freeport coal. It is very nearly 50 feet thick and is fairly massive in the hills east of the town. It is underlain in this region by a thin band of reddish and purple shales.

In the southeastern part of the quadrangle the Saltsburg horizon is for the most part below drainage level, but several apparently carefully kept drill records give an excellent idea of its character. Its top is here 300 feet above the Upper Freeport coal, and it is about 50 feet thick. It is underlain by 30 to 40 feet of shales containing a coal (the Bakerstown bed) or, in one section, two coals separated by 25 feet of shales and sandy shales. Red shale also appears in this shale interval, and not more than 25 feet above this a slightly calcareous bed, very thin, may possibly represent the Upper Cambridge limestone. Both near Johnstown and in the southeastern part of the quadrangle these sandstones in places become sandy shales and merge imperceptibly with the beds above or below, so that it is difficult or impossible to locate their bases and tops in the records.

Buffalo sandstone member.—In the South Fork district the top of the Buffalo sandstone member is about 200 feet above the Upper Freeport coal. As nearly as can be ascertained from the road sections, the sandstone consists of a single member. It appears prominently along the Pennsylvania Railroad near Ehrenfeld, where the débris from it is massive, and is well exposed in the shallow railroad cuts west of Summerhill station. Compactly bedded thick and thin flags are very characteristic of this stratum in the eastern part of the Johnstown quadrangle and farther east in the Ebensburg quadrangle.

Along Blacklick Creek in the northwestern part of the quadrangle there appears in the section a very massive sandstone, whose top is 200 to 235 feet above the Lower Freeport coal and 80 and 95 feet, respectively, above the Mahoning coal and Johnstown ore bed. This sandstone probably corresponds to the Buffalo sandstone member. It is exceedingly massive, forming débris comparable to that from the Pottsville. It makes a very prominent appearance north of Vintondale and to the west in Indiana County.

Gallitzin coal.—The Gallitzin coal ranges from 70 to 125 feet above the top of the Upper Freeport coal in the region around Johnstown. In some of the diamond-drill records from the hills east of the city it appears about 110 feet above the top of the Upper Freeport coal. In some of the sections a coal appears as near the Upper Freeport as 70 feet. Where there is but a single coal in the lower 125 feet of the Conemaugh and it is as near to the Upper Freeport as 70 feet there is always doubt as to whether it should be regarded as the Gallitzin or as a lower coal. The Gallitzin coal is not a commercial bed and has not been worked except for local use in any part of the quadrangle.

Lower red shales.—The Gallitzin coal is underlain by a thin band of red or variegated shales, which are well exposed along the road ascending to Pleasant Hill in the western part of Johnstown. In some records of the drill holes put down to the east of the city these shales have been called variegated.

Mahoning sandstone member.—The Mahoning member is composed of sandstones, shales, and coals lying at the base of the Conemaugh formation between the Gallitzin coal and the Upper Freeport coal (top of the Allegheny formation). It is well exposed in the hills about Johnstown and to the south along Stony Creek, near South Fork, and near Blacklick Creek.

At the tunnel of the Baltimore and Ohio Railroad south of Johnstown the following clear-cut section of the lower part of this member was obtained:

A. SOUTH FORK AND WASHED AWAY DAM.

The breaking of this dam caused the Johnstown flood of May 31, 1889.

B. SANDSTONE NEAR BASE OF CONEMAUGH FORMATION NEAR JOHNSTOWN.

Section of part of Mahoning sandstone member south of Johnstown, Pa.

	Ft.	in.
Sandstone, laminated and cross-bedded, upper Mahoning	8	
Shale, green	4 -5	
Coal		5
Shale, drab, fossiliferous	2	
Coal		6
Fire clay, dark, almost black		6
Limestone, blue, ferruginous, altering to ore ("Johnstown ore")	1½-2	
Shale	30	
Sandstone, massive	20	
Shale, massive, brown	5	

This section may be considered fairly typical for this immediate region. The upper sandstone, called upper Mahoning, is decidedly characteristic in appearance. It is fine grained, weathering into extremely thin slabs, and where seen to greatest advantage ranges in thickness up to 20 feet. The coal below it, exposed in the saddle in the road above the tunnel, is present in two benches with an interval of 2 feet between. This is probably the Mahoning coal. It is nowhere of workable thickness in this quadrangle.

The "Johnstown ore" underlies the Mahoning coal and is about 50 feet above the Upper Freeport coal. As a workable ore it has been found only in the center of the Johnstown Basin. It has been worked in the hills about the city, on Hinckston Run, at the west base of Laurel Ridge, and on Mill Creek. At present it is of no importance.

Flint clay occurs in the shale interval lying above the lower Mahoning sandstone. It lies close to the top of the lower sandstone bed at an interval ranging from 50 to 80 feet above the Upper Freeport coal. The position of this flint clay is shown in the section in the hill east of Johnstown (p. 116). Its characteristics are described later (pp. 115–117).

The lower Mahoning sandstone outcrops in all the hills about Johnstown and has been quarried for building stone at many places. It is very massive, decidedly coarse grained, and micaceous. As a rule it ranges from 20 to 30 feet in thickness and is separated from the top of the Upper Freeport coal by 5 to 10 feet of dark-brown shale.

Near South Fork the base of the Conemaugh is well shown in a recent cut on the Pennsylvania Railroad near Ehrenfeld. A hand-leveled section obtained opposite the station is as follows:

Section of the base of Conemaugh formation at Ehrenfeld.

	Ft.	in.
Shale, weathering to clay	15	
Shale, olive and drab, locally sandy	30	
Coal		4-5
Shale	8	
Shale, black		2

	Ft.
Shales, blue and black	1
Coal	2
Shales	15
Shale, blue, with alternating layers of fine-grained sandstone	20
Sandstone, massive	20
Upper Freeport coal.	

The Mahoning coal appears in this section, as in that south of Johnstown, in two benches at approximately the same distance above the top of the Upper Freeport coal. The lower bench is thick enough to be worked, though so far as known no coal has ever been obtained from it. The lower Mahoning sandstone is fairly massive, but not so much so as in the hills near Johnstown.

In the hills bordering Blacklick Creek, near Wehrum, the Mahoning coal measures about a foot in thickness and is closely underlain by old ore benches, indicating the formerly extensive workings on the Johnstown iron-ore bed. The underlying flint clay is present north, west, and southwest of Wehrum in a position similar with respect to the lower Mahoning sandstone to that of the flint clay occurring above the same sandstone near Johnstown, and is thus to be correlated with that stratum. The lower Mahoning sandstone is persistent where it appears above drainage level in the Blacklick Creek district, and is fairly massive.

ALLEGHENY FORMATION.

GENERAL CHARACTER.

The Allegheny formation was originally known as the "Lower Productive Coal Measures." As may be inferred from that name, it is distinguished from the overlying formation by the presence of several workable coal beds. It is the most important formation in the Johnstown quadrangle, as in it are found all the workable coals of the area. The following section, compiled from the area about Johnstown and to the south, gives an idea of the general character of the formation in this quadrangle:

Section of Allegheny formation about Johnstown and to the south.

		Ft.	In.
Coal, Upper Freeport (Coke Yard or E coal)		3	3
Shale		14	
Shale with limestone concretions		10	
Shales, bluish		25	
Sandstone, laminated		5	
Shales and sandy shales		10	
Coal, 1 foot Bone, 1½ inches Coal, 1 foot 7 inches Bone, 1 inch Coal, 3½ inches	Lower Freeport (D or Limestone coal).	3	1

		Ft.	in.
Limestone		3¼	
Shale, blue		5	
Shale, light drab, ferruginous		7	
Shale, sandy		8½	
Shale, blue black		4	
Coal, Upper Kittanning (C′ or Cement coal)		3¼	
Shale		1	
Limestone		5	
Shale		3½	
Shale, sandy		5	
Shale, black and brown		3	
Coal		1	
Shales, sandy		5	
Shales		20	
Coal		11	
Shale		25	
Interval, chiefly sandstone		20–25	
Coal, 3 feet 8½ inches	Lower Kittanning (Miller or B coal).	5	2½
Bone or black shale, 3½ inches			
Coal, 3½ inches			
Bone, 1 inch			
Coal, 10 inches			
Fire clay		4½	
Sandstone, gray, laminated		9	8
Sandstone, massive		40	
Shale		2	
Coal and bone (Clarion or A′ coal)		3	1
Shale		10	
Sandstone, blue, laminated		5	
Pottsville.			
		280	9½
		to 285	9½

A section of the base of the Allegheny in which both the Brookville and Clarion coals show is as follows:

Section of lower part of Allegheny formation near A. J. Haws & Sons' brick plant, Coopersdale.

	Ft.	in.
Shale, dark	10+	
Coal	1	0–4
Shale, black, with siliceous limestone concretions	10	
Coal		5½
Shale and bone		4
Coal	1	0–5
Shale and bone		0–10
Pottsville sandstone, massive.		

The thickness of the Allegheny ranges from 220 to 290 feet. At its top is the Upper Freeport coal; at its base the Brookville coal. The former occurs almost directly below the massive Mahoning sandstone; the latter rests directly on the top of the even more massive Pottsville—circumstances which in this particular area are helpful in determining the boundaries of the formation.

The more characteristic members of the Allegheny formation occurring in the Johnstown quadrangle are the following:

Upper Freeport coal (E).
Upper Freeport limestone member.
Bolivar clay member.
Butler sandstone member.
Lower Freeport coal (D).
Lower Freeport limestone member.
Upper Kittanning coal (C′).
Johnstown limestone member.
Coals between the Upper Kittanning and Lower Kittanning coals.
Lower Kittanning coal (B).
Lower Kittanning clay member.
Kittanning sandstone member.
Clarion coal.
Brookville coal.

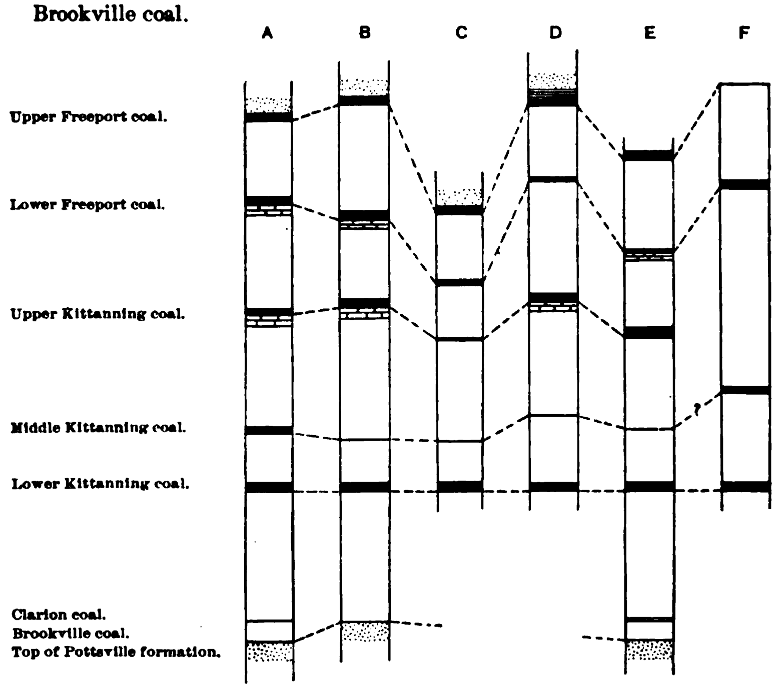

FIGURE 2.—Skeleton sections showing coals in the Allegheny formation. Vertical scale, 1 inch=100 feet. A, Compiled section near Coopersdale; B, compiled section on Peggys and Clapboard runs; C, section north of South Fork; D, section south of South Fork; E, compiled section near southern border of quadrangle; F, section on Blacklick Creek.

The position of the coals with reference to one another in the different districts is well shown in figure 2.

A. EXPOSURE OF LOWER FREEPORT COAL ON STONY CREEK, NEAR TROLLEY BRIDGE.

The overlying sandstone is the Butler. The Lower Freeport limestone member shows below the coal.

B. COUNTRY BANK OF THE BETTER CLASS ON THE UPPER KITTANNING COAL NEAR MINERAL POINT.

DETAILED DESCRIPTION.

Upper Freeport coal.—The Upper Freeport coal lies at the top of the Allegheny formation, almost directly below the massive Mahoning sandstone member and from 220 to 290 feet above the top of the Pottsville formation, or, as it is locally called, the "Conglomerate Rock." It is known in the Johnstown district as the Upper Freeport or E bed but most commonly as the Coke Yard coal. In the South Fork district it is called the Lemon or Four-foot coal. Its chemical and physical characteristics will be discussed in subsequent parts of this bulletin, as will be the case with the other workable coals.

Upper Freeport limestone member.—In the region near South Fork the Upper Freeport limestone appears in the section. A short distance east of Ehrenfeld it is well exposed in some recent excavations along the Pennsylvania Railroad, in which it ranges from 1½ to 3 feet in thickness. It is a gray limestone and very irregularly bedded. (See section, p. 65.)

Bolivar clay member.—A flint clay lying a few feet below what is regarded as the Upper Freeport coal was seen at a few places in the valley of Mardis Run, near the northwestern edge of the quadrangle. This clay probably corresponds with the Bolivar fire clay of the region to the southwest. Two feet of clay was seen at one point on the outcrop, and the bed may possibly be thicker.

Butler sandstone member.—In some places on Stony Creek a very massive sandstone 20 feet thick was observed lying directly over the Lower Freeport or D coal. (See Pl. IV, *A*.) This corresponds in position to the Butler or "Upper Freeport" sandstone. It is very local in its development.

Lower Freeport coal.—The Lower Freeport or D coal is known about Johnstown as the Limestone bed from a 2 to 3 foot bed of limestone occurring within a foot of its base. In position it ranges from 45 to 70 feet below the Upper Freeport coal. (See Pl. IV, *A*.)

Lower Freeport limestone member.—The Lower Freeport limestone occurs either directly below or within a foot of the base of the Lower Freeport coal, the slight interval as a rule being filled with black shale. This limestone shows in Plate IV, *A*.

Upper Kittanning (C′) coal.—The next lower horizon of importance is the Upper Kittanning or C′ coal, known near Johnstown as the Cement coal. It is an important coal near Johnstown and Windber, and in fact is one of the most persistent and valuable coals in the quadrangle. It occurs from 80 to 105 feet below the Upper Freeport, though near South Fork this interval is less. Above the Upper Kittanning coal, near Johnstown and to the west on Dalton Run, some of the sections show one and some two small coals. These sections follow.

Section of Upper Kittanning coal at mouth of Rolling Mill mine of Cambria Steel Company, Johnstown, Pa.

	Ft.	in.
Sandstone, thin bedded	3	
Coal		2–4
Sandstone, thin bedded and laminated	8	
Shale		6
Coal, Upper Kittanning (C′)	3	
Shale	1	
Limestone	4+	
Shale or fire clay	2–4	

Section of Upper Kittanning (C′) coal on Dalton Run.

	Ft.	in.
Shale.		
Coal		4
Shale		10
Coal		4
Shale	3	
Coal	4	
Shale or clay	2+	
Limestone bowlders.		

Johnstown limestone member.—About Johnstown the Upper Kittanning coal is underlain by a limestone which may prove suitable for the manufacture of cement. This cement bed is best developed along Stony Creek and may be seen to advantage in the cuts on the Baltimore and Ohio Railroad north of Kring, where it is 6 feet thick and is separated from the coal by 8 to 12 inches of shale. Along the spur track leading from the north end of the tunnel into the Valley Coal and Stone Company's mines it is also conspicuous but is slightly thinner. An analysis of this cement rock is given on page 128. It is shown in Plate VII, *A* (p. 48).

Coals between the Upper and Lower Kittanning coals.—In several of the sections south of Johnstown a coal bed occurs from 17½ to 20 feet below the base of the Upper Kittanning coal. This coal is very thin, in most places measuring less than 6 inches. It may be seen in the bluffs near the Citizens Eighth Ward mine and in the cut on the Baltimore and Ohio Railroad north of Kring. At the latter place another coal 7½ inches thick appears in the section 13 feet below the upper thin coal and about 31 feet below the base of the Upper Kittanning bed. What is probably the upper of these two coals appears in many of the drill records from the Wilmore Basin, and both are persistent in the section along the main line of the Pennsylvania Railroad east of East Conemaugh. In the latter region, however, the lower coal, which it is thought must be the representative of the Middle Kittanning (C) coal, lies 45 to 50 feet below the base of the Upper Kittanning—a distance greater than at Kring. Near the brick plant of A. J. Haws & Sons (Limited), at Coopersdale, what is tentatively regarded as the Middle Kittanning occurs 25 feet above the Lower Kittanning bed.

Lower Kittanning coal.—The next lower coal—the Lower Kittanning, Miller, White Ash, or B coal—is the most persistent and valuable bed in the area. It usually lies approximately 145 to 200 feet below the Upper Freeport coal and from about 65 to 100 feet above the top of the Pottsville.

Lower Kittanning clay member.—The Lower Kittanning clay is the most valuable plastic clay in the area. It usually underlies the lower bench of the Lower Kittanning coal, from which it may be separated by a few inches of shale. In the absence of the lower bench of coal it sometimes occurs below the main coal itself, being separated from it by 3 to 4 inches of bone or shale. (See, further, pp. 117-118, 123.)

Kittanning sandstone member.—On the Baltimore and Ohio Railroad, between Foustwell and the mouth of Paint Creek, on the west flank of the Ebensburg anticline, the Pottsville and the beds below the Lower Kittanning coal are well exposed. Near the water tank and culvert nearly a mile east of the bridge over Stony Creek the following section was measured:

Section of the lower part of the Allegheny formation, east of Foustwell.

	Ft.	in.
Base of Lower Kittanning coal:		
Fire clay	4	8
Sandstone, laminated	9	8
Sandstone, massive	40	
Shale	2	
Coal		6
Shale, black		6
Coal	2	7
Shale	10	
Sandstone, blue, laminated	5	
Pottsville sandstone, massive.		

Brookville and Clarion coals.—Between the Lower Kittanning coal and the top of the Pottsville formation are found either one or two coals. The coal noted in the preceding section is one of these, possibly the upper or Clarion bed; where the section was taken it is of workable thickness. Both coals appear at the roadside near A. J. Haws & Sons' brick plant, west of Coopersdale. (For section, see p. 23.) The lower coal, consisting of two benches, is the Brookville; the higher is regarded as the Clarion. Representatives of these lower coals are found near Twin Rocks.

POTTSVILLE FORMATION.

The Pottsville, where most plainly developed in the Johnstown quadrangle, consists of three members—an upper and a lower sandstone, known respectively as the Homewood and Connoquenessing sandstone members, and an intervening shale (containing a coal bed), known as the Mercer shale member. With these is associated an important flint clay.

A section of the Pottsville along Stony Creek, in part off the southern edge of the quadrangle, is as follows:

Section of Pottsville formation in and near Johnstown quadrangle.

	Feet.
Sandstone, massive (Homewood)	65–90
Shale, black, and clay (Mercer)	11
Sandstone, massive (Connoquenessing)	95–105

This gives a total thickness to the Pottsville of about 170 feet. Between South Fork and Mineral Point the thickness of the Homewood member, where it could best be observed, is only about 35 feet, indicating a thinning to the east; the thickness of the whole formation, however, remains at about 170 feet. In the South Fork district the Mercer interval contains a valuable flint clay.

The Pottsville is not always devoid of coal, as the section given above might indicate. South of Kring the Mercer contains a coal bed whose section is given on page 61. At the B. H. Campbell shale quarry, on the Mercer (p. 119), coal is also present.

The sandstones of the Pottsville are massive and coarse grained but rarely conglomeratic. They make very large sandstone débris, and the country underlain by the Pottsville is usually wilderness.

MISSISSIPPIAN SERIES.

MAUCH CHUNK SHALE.

Evidences of an unconformity at the top of the Mauch Chunk are to be seen in the Johnstown quadrangle. The Mauch Chunk is well exposed along the flanks of the Ebensburg anticlinal axis on Stony Creek, near the bridge at the mouth of Paint Creek, and also south of the quadrangle. It is also well shown at the viaduct along the flanks of the Viaduct or Ebensburg anticline (Pl. V, *A*), farther west in the gorge of Conemaugh River, and on the sides of Laurel Ridge, where it is brought above drainage level by the Laurel Ridge anticline. The upper 50 feet of this formation is exposed in the valley of South Branch of Blacklick Creek, near Twin Rocks.

A section of the upper part of the formation, obtained on Stony Creek about a mile above the mouth of Paint Creek, is as follows:

Section of upper two members of Mauch Chunk shale near mouth of Paint Creek.

	Ft.	In.
Shales, red	6–21	
Sandstone, heavy	10	8
Shale, red	20	
Sandstone, vivid green	3	
Shales, red and green	13–15	
Shale, green	1	
Shale, blue-green, sandy	5	4
Sandstone, green, usually laminated and cross bedded	44+	

A. TYPICAL EXPOSURE OF MAUCH CHUNK SHALE AT THE VIADUCT BETWEEN SOUTH FORK AND MINERAL POINT.

Note the alternating thin layers of sandstone and shale and the vertical jointing.

B. SHALE QUARRY OF B. H. CAMPBELL AT THE MERCER HORIZON NORTH OF SHERIDAN.

The rounded bowlders in the foreground are probably of Pleistocene age.

A. DETAILED STRUCTURE OF LOYALHANNA LIMESTONE AT THE TOP OF THE POCONO FORMATION, EAST OF MINERAL POINT.

Weathering has brought out the cross-bedding of the rock.

B. LOYALHANNA LIMESTONE, TOP MEMBER OF POCONO FORMATION, AT SUMMIT OF EBENSBURG (VIADUCT) ANTICLINE, MINERAL POINT.

Near the viaduct the lower green laminated and cross-bedded sandstone member given in the section appears, dividing, as it were, the Mauch Chunk into an upper and lower shaly member. It may represent the Greenbrier limestone in this region. This sandstone at the viaduct was measured in its entirety and was found to be 42 feet thick. The lower shale division at the viaduct is 40 feet, giving to the members of the Mauch Chunk the following thicknesses:

Section of Mauch Chunk shale at the viaduct.

	Feet.
Upper shaly member	60–75
Sandstone	44+
Lower shale member	40

Thus the Mauch Chunk in this quadrangle may be considered approximately 160 feet thick.

POCONO FORMATION.

The upper part of the Pocono shows in the bed of Conemaugh River between the viaduct and Mineral Point. It is made up of the Loyalhanna limestone member, about 45 feet of which is here exposed. (See Pl. VI, *A* and *B*.) The entire formation is above drainage level in the gorge of Conemaugh River west of Johnstown. It is brought above water level by the Laurel Ridge anticline and covers part of the ridge both south and north of the river. Though it is not exposed so as to be measured in detail, the barometer indicated from the top of the red Catskill beds to the red shales of the Mauch Chunk overlying the Loyalhanna limestone a thickness of 1,085 feet, which it is believed closely approximates the thickness of this formation in the region. This is slightly greater than the figures obtained by Charles Butts and the writer [a] on the Allegheny Front. There is no reason to suppose that the Pocono here differs much from that on the Allegheny Mountain east of Bennington.

DEVONIAN SYSTEM.

CATSKILL FORMATION.

But 400 feet of Devonian rocks are exposed in the Johnstown quadrangle, and these occur at the top of the Catskill, in the gorge of Conemaugh River where it is crossed by the Laurel Ridge anticlinal axis. The Catskill beds are prevailingly red and green shales and red sandstones and color the soil a distinct red. The upper part of the formation was measured by the writer as follows:

[a] Ebensburg folio (No. 133), Geol. Atlas U. S., U. S. Geol. Survey, 1905, p. 3.

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[a] Ebensburg folio (No. 133), Geol. Atlas U. S., U. S. Geol. Survey, 1905, p. 3.

Section of upper portion of Catskill formation on Conemaugh River.

	Feet.
Sandstone, chocolate and reddish	45
Shale, red	20
Sandstone, chocolate-colored	5
Shales, chocolate and vivid green	40+

STRUCTURE.

MODE OF REPRESENTATION.

The inclination of the beds to a horizontal plane, or the dip, as it is commonly called, is measured in the field by means of a clinometer where the inclination is great enough to permit it. In but few localities in the Johnstown quadrangle, however, are the dips sufficient to allow this mode of measurement. Where it is not applicable continuous road sections are run and the beds are correlated from hillside to hillside. When the elevation above mean sea level of a sandstone, coal, or limestone on one hill and its elevation a mile or so away have been found, the rise or fall of this particular bed in feet per mile is at once obtained. By connecting points of equal elevation on any selected bed the contour lines for that bed are drawn. On the map, Plate I, the contour interval is 50 feet and all points on the plane selected (the base of the Lower Kittanning or B coal) that are multiples of 50 are connected by light-brown lines.

The base of the Lower Kittanning coal was selected as the bed on which to draw structure contours in the Johnstown quadrangle because this is commercially the most important coal and the most persistent. Moreover, its relations to the beds both above and below it are fairly well known.

To draw contours on the bed where it is above drainage level and is worked is easy, for it is necessary simply to obtain its elevation from point to point where it outcrops and then to connecting points of equal elevation. But where the coal fails to appear above drainage level other means of determining its elevation have to be employed, and its distance below other known beds that do appear must be used as a basis for calculation, it being assumed, of course, that this distance is constant within the areas where this method is employed. Conversely, where the dips are so great as to carry the horizon of the coal above the hilltops its interval above known beds must be used. When the latter two methods are employed in contouring great precision is not obtainable, as intervals are subject to variation in any region and are known to vary greatly within comparatively short distances in the Johnstown quadrangle. Furthermore, most of the elevations in this work are obtained by means of the aneroid barometer, which, as is well known, is liable to sudden variations and has to be constantly checked against spirit-leveled elevations.

The structure contours not only show the generalized surface formed by the Lower Kittanning coal but less precisely the lay of the underlying and overlying beds. The contour interval chosen is 50 feet and the limit of error may be considered a contour interval, but where the beds vary in thickness it may be more than this. This mode of representing the structure makes it possible to estimate approximately the elevation of the top of the Lower Kittanning coal where it is below the surface at a given point, and hence to find its depth below the surface at that point; furthermore, if the intervals of other coals either above or below the Lower Kittanning are known, their depth at any particular point may be readily computed.

STRUCTURE IN THE JOHNSTOWN QUADRANGLE.

GENERAL STATEMENT.

The beds described under the heading "Stratigraphy" (pp. 14–30) are involved in a series of parallel folds having a general northeast-southwest trend and extending completely across the area in a series

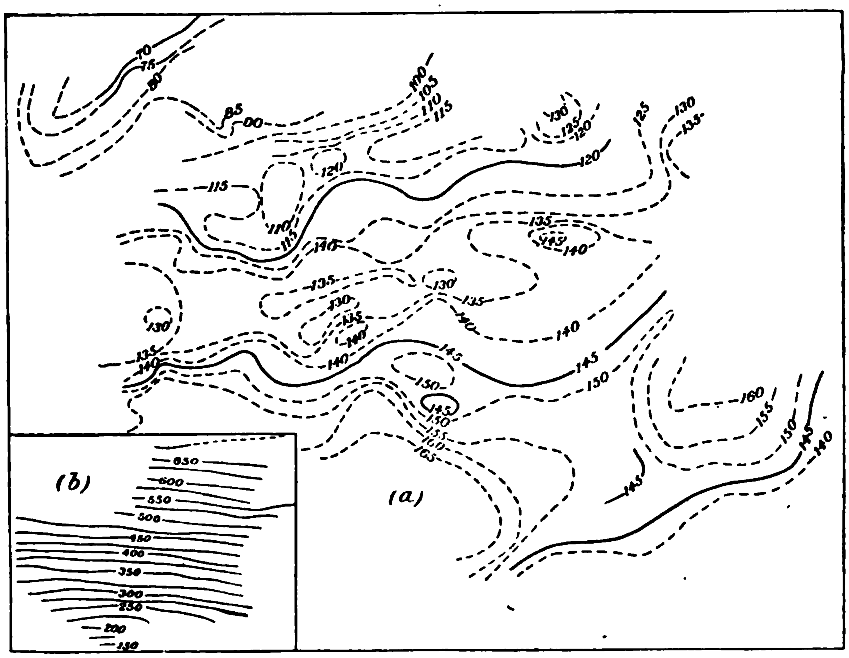

FIGURE 3.—Sketch showing (a) the great irregularity in detail of the structure in some parts of the Johnstown quadrangle and (b) the marked regularity in detail in other parts. In b the 5-foot contour lines are omitted to avoid crowding, but were they inserted the regularity would appear almost as pronounced.

of waves from the southeast to the northwest part of the quadrangle. The structure as worked out differs in some particulars from that described by the Second Survey of Pennsylvania, the most notable difference perhaps being in the offset of the Johnstown Basin to the east near Johnstown (Pl. I). In the map of the Second Survey the axis of the Johnstown syncline or basin is represented as being west of the South Fork of Bens Creek; it is believed that it really lies farther to the east.

Viewed broadly, the structure is very regular in the Johnstown quadrangle, as will be seen from the structural contour map (Pl. I). In detail it may be decidedly irregular. (See fig. 3.)

The structural features in the Johnstown quadrangle, beginning in the southeast corner and proceeding to the northwest, are—

Wilmore syncline.
Viaduct or Ebensburg anticline.
Johnstown syncline.
Laurel Ridge anticline.
Westover or Barnesboro syncline.

In the reports of the Second Geological Survey of Pennsylvania the Wilmore and Johnstown basins were designated subbasins and were considered to constitute part of the first bituminous coal basin. The Viaduct anticline was called a subaxis and the Laurel Ridge anticline was designated the first grand axis of the bituminous coal regions.[a] D'Invilliers[b] somewhat changed the usage, as he speaks of the first and second basins, referring to the Wilmore and Johnstown basins, respectively. The terms syncline and basin or trough are of course synonymous, as are also the terms anticline and arch.

DETAILED DESCRIPTION.

Wilmore syncline.—The Wilmore Basin or syncline is so called from the town of Wilmore, situated on the Pennsylvania Railroad a short distance east of Summerhill, in the Ebensburg quadrangle. It is a comparatively long and narrow synclinal trough parallel with and west of the Allegheny Front. The position of the axis of the basin is definitely fixed near the town of Wilmore by the opposing dips of the rocks along the old track of the Pennsylvania Railroad. As indicated on Plate I, the axis enters the Johnstown quadrangle northeast of the old reservoir site on South Fork of Conemaugh River and continues southeast, passing near the town of Elton. It leaves the quadrangle in a line almost coincident with the South Fork branch of the Pennsylvania Railroad. On the southeast side of this axis the beds dip northwest, and on the northwest side the beds dip southeast. In the quadrangle all the beds along the axis dip northeast, as the axis plunges in that direction. The rise of the beds to the southwest is rapid, amounting to 900 feet in a distance of 16 or 17 miles, so that the Lower Kittanning coal, which is between 800 and 900 feet above the sea and hence far below drainage level in the center of the basin,

[a] Second Geol. Survey Pennsylvania, Rept. H2, pp. xxix, 25, 26.
[b] Summary Final Rept. Geol. Survey Pennsylvania, 1895, p. 2219.

outcrops at an elevation of about 1,700 feet at the mines about Windber.

Viaduct anticline.—The Viaduct or Ebensburg anticline is the next structural feature to the west. Its axis has a general northeast-southwest direction, but swerves slightly to the southeast and then again to the southwest in the part of the quadrangle south of Conemaugh River. This offset, however, is not at all marked.

The Lower Kittanning coal and associated beds, so deeply buried in the center of the Wilmore Basin, rise rapidly and with great regularity to the west and outcrop in the valley of Conemaugh River at South Fork. From its deepest point in the Wilmore syncline the coal rises more than 1,000 feet to its highest point on the summit of the Viaduct or Ebensburg anticline. The lowest bed brought above drainage level by this rise is the top member of the Pocono formation (the Loyalhanna limestone member), which outcrops along the summit of the arch, between the viaduct and Mineral Point. (See Pl. VI, *A* and *B*.)

Johnstown Basin.—The Johnstown Basin or syncline, which is the next structural feature to the west, comprises the area between the Viaduct and Laurel Ridge anticlinal axes. It is really made up of two basins in this quadrangle, one in Cambria and one in Somerset County. It has a general northeast-southwest course but is sharply offset to the east in the vicinity of Johnstown. (See Pl. I.) The axis in Somerset County trends in the usual northeast-southwest course. The dip of the beds on the east side of the basin is comparatively gentle, the fall being approximately 900 feet in 9 miles, or at the rate of 100 feet per mile from the summit of the Viaduct anticline at the viaduct to the deepest part of the basin north of Conemaugh River. In the southern part of the quadrangle the corresponding drop is only 700 feet. On the west side of the basin the rise of the beds to the Laurel Ridge axis is sharp—between 2,000 and 2,100 feet in a distance of 9 miles along Conemaugh River—producing the maximum dips in the quadrangle. In addition to their inclination from the northwest and southeast to the center of the basin, the beds north of Conemaugh River dip gently to the northeast. The Johnstown synclinal axis and the Ebensburg anticlinal axis approach each other near the northeast corner of the quadrangle.

Laurel Ridge anticline.—The Laurel Ridge anticline is the major structural feature in the Johnstown quadrangle, and, as stated on page 32, it is the "first grand axis" as described by the Second Geological Survey of Pennsylvania. It crosses Conemaugh River about midway between Conemaugh Furnace and Coopersdale and passes to the northeast, crossing South Branch of Blacklick Creek a little over a mile southeast of Twin Rocks. Where the axis of the fold crosses the valley of Conemaugh River the lowest beds in the quadrangle—the red shales and sandstones of the Catskill formation, aggregating 400 feet or more above drainage level—are exposed. The fold pitches sharply to the northeast, and the Pocono formation, which caps the hills where the axis crosses Conemaugh River, is below drainage level where it crosses South Branch of Blacklick Creek near Twin Rocks, dropping in this distance at least 1,000 feet. As stated in the description of the Johnstown Basin, the beds along the eastern flank of the Laurel Ridge anticline rise between 2,000 and 2,100 feet in a distance of 9 miles. The fall in the beds west of the anticlinal axis to the Barnesboro or Westover Basin is at about the same rate. The anticline is therefore symmetrical.

No beds of coal are present at the summit of the ridge and none occur below its surface until Blacklick Creek is approached. The coals have, so to speak, been carried out into the air by the rise in the beds on either side of the anticlinal axis.

Barnesboro or Westover syncline.—The basin west of the Laurel Ridge anticline is termed the Westover Basin in the Pennsylvania Geological Survey reports. More recently it has been called the Barnesboro Basin by members of the United States Geological Survey.[a] The axis of the basin enters the Johnstown quadrangle near the line between Cambria and Indiana counties, passes through or very near Wehrum, and leaves the quadrangle as indicated on Plate I. From the axis of this basin the beds rise gently to the axis of the Nolo anticline, which just cuts the northwest corner of the quadrangle.

Minor structures.—Besides the principal folds, there are many minor folds in the rocks of the quadrangle. A small arch or anticline is exposed along Little Conemaugh River about a mile east of Conemaugh station. From this point westward to the Johnstown station there are many minor fluctuations, all exposed along the main line of the Pennsylvania Railroad. Between Millville and Coopersdale there is a distinct anticline. Thus it appears that the main broad Johnstown syncline has been subjected to many minor plications. It has been thought by some mining men that to these lesser folds about Franklin and along Clapboard Run is due the so-called faulting which the coal exhibits in this region. The erratic behavior of the Lower Kittanning coal in this locality may possibly be due in part to this cause, but the irregularities seen by the writer are not faults as this term is used in the geologic sense, but are rather broad rolls which seem to have squeezed out the coal. In some places the conditions during sedimentation were such that coal was not deposited or, if deposited, was afterward removed.

[a] Campbell, M. R., and Clapp, F. G., in an unpublished manuscript relating to the Barnesboro quadrangle, which lies north of the Johnstown quadrangle.

MINERAL RESOURCES.

INTRODUCTION.

The mineral resources of the Johnstown quadrangle are coal, flint and plastic clay, shales, limestone and cement material, building stone, glass sand, and iron ore. Because of the great importance of coal and clay they will be treated (1) in a broad way for the sake of the general reader who may be interested in the area as a whole but not in any particular portion of it, and (2) in detail by districts. The remaining resources—limestone and cement material, building stone, glass sand, and iron ore—will be treated as a whole, as their description by districts would involve needless repetition.

COAL.

GENERAL DESCRIPTION.

UPPER FREEPORT COAL.

The highest important coal in the Johnstown quadrangle is known as the Upper Freeport. It is used as a domestic and steam fuel about Johnstown and South Fork and supplies some of the brick plants at Johnstown. It gives satisfactory results, particularly when used in locomotives. It is not coked in this quadrangle, though at Cresson, Gallitzin, and Bennington it gives satisfactory results in beehive ovens. In the by-product ovens of the Cambria Steel Company at Franklin, near Johnstown, it was found to be unsuitable owing to expansion, which quickly ruined the ovens and made it very difficult to force out the charge after it was coked. The analyses of this coal as given on page 40 show it to be a high-carbon coal with very low moisture content. The ash, especially in the Johnstown Basin, is high; its sulphur content, ranging from 2 to 2½ per cent, is also rather high.

LOWER FREEPORT COAL.

The Lower Freeport or D coal is of workable thickness about Johnstown, and, though not exploited at present, it will probably become one of the important coals of the Johnstown district. Its percentage of carbon is high.

UPPER KITTANNING (C′) COAL.

The Upper Kittanning or C′ coal is one of the most valuable beds about Johnstown and its suburbs, where it is known as the Cement bed. To the south, about Windber, prospecting has shown it to be even thicker than about Johnstown. As a steaming coal it is probably equal if not superior to any other coal in the Johnstown

Basin, and the recent demand for it has been greater than the supply. The six analyses (p. 40) show a high-carbon coal with correspondingly low volatile matter. The moisture is low, but the ash and sulphur are rather high. The coal mined from this bed at Franklin mine No. 1 of the Cambria Steel Company is washed and coked at the Franklin plant. It makes a coke of good grade, but owing to its low volatile matter it is not considered so well adapted for beehive ovens as some of the richer gas coals of the districts farther west. In view of the cost of shipping coke from the region about Connellsville and Pittsburg, it is cheaper to wash and coke this coal on the ground. The coal is worked also in a small way near South Fork.

LOWER KITTANNING (MILLER) COAL.

CHARACTER AND IMPORTANCE.

The next lower coal of importance in this area is the Lower Kittanning or B coal, also widely known as the Miller seam. This is the most persistent of the valuable coals of the area. From the analyses on pages 40–42 it will be seen that its fixed carbon ranges from 68 per cent in sample No. 24, collected at Wehrum, Indiana County, to more than 78 per cent in samples collected at South Fork. Its volatile matter ranges from 14 to 19 per cent. Its moisture is low; only a few analyses show more than 3 per cent and in none of them does it exceed 4 per cent. The ash and sulphur exhibit considerable variation, as might naturally be expected in view of the wide extent of the territory from which the samples were collected. The samples from South Fork have the lowest content both in sulphur and ash and show the excellent character of the Lower Kittanning bed in this part of the Wilmore Basin. As a steam coal it ranks among the very best in western Pennsylvania, the coal mined about South Fork probably equaling any other steam coal in this part of the State. As bearing on this point the following table has been prepared, showing its position among the 120-odd coals tested at the fuel-testing plant of the United States Geological Survey at St. Louis, Mo., since the summer of 1904.[a] The column recording the number of pounds of water evaporated by 1 pound of dry coal from and at a temperature of 212° F. gives the comparative results of the coals tested so far as these relate to their commercial value.

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[a] Bull. U. S. Geol. Survey No. 261, 1905, and No. 290, 1906.

Chemical composition and steaming values of typical Appalachian coals.

Location.	Number of tests made.	Average chemical composition.					Average pounds of water evaporated from and at 212° F. per pound of dry coal.
		Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	
Page, Fayette County, W. Va	2	4.06	30.35	61.54	4.05	0.90	10.545
Do	1	2.85	30.13	64.78	2.24	1.06	10.52
McDonald, Fayette County, W. Va	2	2.75	20.59	70.05	6.61	.98	10.36
Big Black Mountain, Harlan County, Ky	2	5.06	34.77	56.31	3.86	.56	10.26
Rush Run, Fayette County, W. Va	2	2.12	21.91	70.73	5.24	.67	10.195
Ehrenfeld, Cambria County, Pa	5	2.38	16.53	74.47	6.62	.95	10.186
Winifrede, Kanawha County, W. Va	4	3.79	35.33	55.76	5.12	1.11	10.16
Acme, Kanawha County, W. Va	4	2.93	32.66	57.64	6.77	1.23	10.115
Powellton, Fayette County, W. Va	1	3.42	31.11	59.47	6.00	.82	10.09
Near Bretz, Preston County, W. Va	3	4.20	28.05	60.86	6.89	1.28	10.07

The results of tests on the Ehrenfeld samples, although showing a range of 9.75 to 10.42 pounds of water evaporated per pound of dry coal used, are yet, when averaged, among the very best obtained at the testing plant. Each sample submitted to the steaming test was analyzed, and the accompanying analyses represent averages of the total number made, as do the figures representing the efficiency of the coals as steam producers. It is of interest to note that the Ehrenfeld coal contains the largest percentage of fixed carbon and the lowest amount of volatile matter of all the samples.

Other samples of the Lower Kittanning coal tested by the United States fuel-testing plant from January 1, 1906, to June 30, 1907, include a few from in or near this quadrangle. The results of these tests are given below, together with the analyses of the samples tested. For comparison the results (given above) from the Ehrenfeld coal are repeated.

Chemical composition and steaming values of typical Appalachian coals.

Location.	Number of tests made.	Average chemical composition.					Average pounds of water evaporated from and at 212° F. per pound of dry coal.
		Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	
Wehrum, Blacklick Creek district, Indiana County [a]	2	2.17	17.58	69.81	10.45	4.62	9.19
Lloydell, Cambria County (southeast of quadrangle) [b]	2	5.00	19.05	66.78	9.18	1.53	[c] 9.52
Near Seward, Conemaugh Furnace district, Westmoreland County [d]	2	3.15	20.55	67.75	8.56	1.79	[c] 8.90
Ehrenfeld, South Fork district, Cambria County	5	2.38	16.53	74.47	6.62	.95	10.186

[a] Bull. U. S. Geol. Survey No. 332, 1908, pp. 201, 202.
[b] Idem, pp. 210, 211. Lloydell is on the east flank of the Wilmore Basin and on the quadrangle to the east.
[c] Test made on briquets from the coal.
[d] Bull. U. S. Geol. Survey No. 332, 1908, pp. 216, 217.

The figures obtained in the last column give comparative commercial values which show the high grade of the Lower Kittanning coal as coal or in briquet form in and near the quadrangle. It is of interest to see how the analysis and steaming values of the coal collected at Lloydell on the east flank of the Wilmore Basin compare with the results obtained near Seward in the area to the west. For the details of the conditions governing these steaming tests the reader is referred to Bulletin 332.

COKING TESTS.

The Lower Kittanning (Miller) coal is coked, but it does not rank so high as a coking coal as it does as a steam producer. Tests on samples yielded the following results:

Coking tests on Lower Kittanning coal in Johnstown quadrangle.

	1.	2.	3.	4.	5.
Duration of test ... hours	51	61	54	68	78
Size as used	(a)	(a)	(b)	(a)	(a)
Coal charged ... pounds	10,000	9,750	12,460	13,070	11,760
Coke produced ... pounds	5,223	5,779	8,144	8,129	7,350
Coke produced ... per cent	52.23	59.27	65.36	62.20	62.50
Breeze produced ... pounds	1,600	262	332	420	529
Breeze produced ... per cent	16.00	2.69	2.66	3.21	4.50
Total yield ... per cent	68.23	61.96	68.02	65.41	67.00

[a] Finely crushed. [b] Run of mine.

Analyses of Lower Kittanning coal and of coke made from it.

	1.		2.		3.		4.		5.	
	Coal.	Coke.	Coal.	Coke.	Coal.	Coke.	Coal.	Coke.	Coal.	Coke.
Moisture	3.32	0.91	7.19	0.56	4.53	0.57	3.91	0.30	6.30	0.51
Volatile matter	15.56	2.16	17.86	.32	18.56	.55	16.35	.28	17.04	.58
Fixed carbon	74.29	88.99	69.57	91.10	70.63	90.23	68.30	84.95	69.58	89.85
Ash	6.83	7.94	5.38	8.02	6.28	8.65	11.44	14.47	7.08	9.06
Sulphur	1.12	.91	1.63	1.46	1.85	1.54	2.78	2.31	1.34	1.11

1. Raw bituminous coal from mine No. 3, Pennsylvania Coal and Coke Company, Ehrenfeld, collected under supervision of J. S. Burrows. Bull. U. S. Geol. Survey No. 290, 1906, p. 181.
2 and 3. Washed run-of-mine coal from Wehrum, collected under supervision of John W. Groves. Bull. U. S. Geol. Survey No. 332, 1908, p. 203.
4. Raw run-of-mine coal from a mine 1¼ miles east of Seward, collected under supervision of John W. Groves. Bull. U. S. Geol. Survey No. 332, 1908, p. 218.
5. Washed run-of-mine coal from same locality as No. 4.

The results obtained from the coking tests were as follows:

The coke from Lower Kittanning coal collected at Ehrenfeld (No. 1) was soft and dense, dull gray in color, with a heavy black butt. It broke in large and small chunks and was difficult to burn. The cell structure was small.

The coke from the first test (No. 2) on the Wehrum sample was soft and dense and dull gray in color. The high content in sulphur is worthy of note. The coke from the second test (No. 3) on the Wehrum sample was light gray or silvery in color and much better than the coke from the finely crushed coal (No. 2). It also was high in sulphur. The coke from the first test (No. 4) on the sample collected 1½ miles east of Seward was light gray or silvery in color and was soft and dense, with high ash and sulphur. The coke from the second test (No. 5) was gray in color; washing produced no change in its physical appearance though it reduced the ash and sulphur slightly. As in the test No. 4, the coke was soft and dense.

It may be added that the yield of coke in all the above tests is high. The coal mined at Franklin (analysis 11, p. 40) is coked by the Cambria Steel Company in by-product ovens for use in the company's plant near Johnstown and gives satisfactory results. The coal is washed before coking, thereby adding to the cost, but even with this additional expense it is found cheaper to coke this coal on the ground than to buy coke of better quality from the Connellsville region. Tests have been made by the Cambria Steel Company with the coal mined from this bed about Ehrenfeld, and the resulting coke proved well adapted to metallurgical purposes. The yield also was satisfactory. The coal mined at Nanty Glo from this bed has been tested in beehive ovens at Gallitzin. It produced coke of good structure but of a rather dull appearance. As was to be expected, an insufficient amount of sulphur was volatilized. At Bennington this coal, like the Upper Freeport, shows a higher content in volatile matter than it does about South Fork and Johnstown. The Lackawanna Coal and Coke Company has experimented with it about Wehrum, but the washeries have been shut down and the results of the coking tests were not learned. The results of Survey tests have already been given (p. 38). The Vinton Colliery Company has erected a by-product plant at Vintondale, and in 1907 a considerable part of the coal mined from colliery No. 6 was coked.

MISCELLANEOUS TESTS.

Other tests have been made on the Lower Kittanning coal, such as producer-gas tests, washing tests, cupola tests, and briquetting tests. The details connected with these are given where this coal is considered in the different districts (pp. 71–76, 83–88, 98–100).

LOWER ALLEGHENY COALS.

The coals below the Lower Kittanning have not been extensively developed in this area. At South Fork a bed lying about 60 feet below the Miller coal and known locally as the Dirty A or Six-foot seam has been opened. It is possible that this corresponds to the Brookville (A) coal of the Allegheny Valley. It has a composition indicated by analysis 36 on pages 41–42, and from the high ash and sulphur content, aggregating more than 15 per cent, deserves the name which is often applied to it. In other respects the analysis corresponds with those of other coals of the area, being relatively high in fixed carbon and low in volatile matter.

COMPOSITION OF THE COALS.

The coals of the Johnstown quadrangle belong to the soft, lustrous, semibituminous variety. They are best adapted for steaming and domestic purposes, but some of them make also an excellent coke. They are classed as smokeless coals because of their small content of volatile hydrocarbons. They are uniformly high in carbon and contain small amounts of volatile matter and moisture. Their ash and sulphur contents are variable but in general terms high compared with other Appalachian coals—for instance, those of West Virginia and eastern Kentucky. Some analyses of samples collected according to present Survey methods are listed below.

Analyses of coal samples from Johnstown quadrangle, Pennsylvania. [a]

	Upper Freeport (E).			Lower Freeport (D).	Upper Kittanning (C').					
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
Sample as received:										
Moisture	2.65	2.82	3.04	4.73	2.81	1.67	2.60	1.94	2.93	3.51
Volatile matter	14.86	15.61	16.27	13.78	15.07	18.52	14.10	15.81	13.47	17.16
Fixed carbon	72.38	70.32	73.47	72.27	72.64	69.14	72.05	70.77	74.06	69.04
Ash	10.11	11.25	7.22	9.22	9.48	10.67	11.25	11.48	9.54	10.29
Sulphur	2.06	2.42	2.18	1.09	1.92	3.46	2.79	3.73	1.88	2.01
Loss of moisture on air drying	2.00	2.10	2.50	4.00	2.20	1.00	2.00	1.20	2.20	2.30
Air-dried sample:										
Moisture	.66	.74	.55	.76	.62	.68	.61	.75	.75	1.24
Volatile matter	15.16	15.94	16.69	14.35	15.41	18.71	14.39	16.00	13.77	17.56
Fixed carbon	73.86	71.83	75.35	75.28	74.28	69.84	73.52	71.63	75.73	70.67
Ash	10.32	11.49	7.41	9.61	9.69	10.77	11.48	11.62	9.75	10.53
Sulphur	2.10	2.47	2.24	1.14	1.96	3.49	2.85	3.78	1.92	2.06

	Lower Kittanning (B).									
	11.	12.	13.	14.	15.	16.	17.	18.	19.	20.
Sample as received:										
Prox. Moisture	2.70	2.03	2.81	1.78	2.21	2.24	2.63	2.79	3.12	3.07
Prox. Volatile matter	15.64	14.47	14.66	15.19	14.32	15.70	17.85	17.76	17.89	17.64
Prox. Fixed carbon	74.03	75.31	75.75	73.25	78.16	78.37	73.24	73.20	70.85	72.85
Prox./Ult. Ash	7.63	8.19	6.78	9.78	5.31	3.69	6.28	6.25	8.14	6.44
Ult. Sulphur	1.93	2.26	1.33	4.50	.47	.77	1.49	1.88	2.74	1.38
Ult. Hydrogen	......	4.14	......	4.16	......	......	......	......	......	......
Ult. Carbon	......	79.97	......	77.10	......	......	......	......	......	......
Ult. Nitrogen	......	1.26	......	1.41	......	......	......	......	......	......
Ult. Oxygen	......	4.18	......	3.05	......	......	......	......	......	......
Calorific value determined:										
Calories	......	7,823	......	7,612	......	......	......	......	......	......
British thermal units	......	14,081	......	13,702	......	......	......	......	......	......
Loss of moisture on air drying	1.80	1.40	1.90	1.10	1.60	1.60	2.00	2.10	2.50	2.50

[a] All analyses given in this paper, unless otherwise stated, were made at the fuel-testing plant of the United States Geological Survey at St. Louis, Mo.: J. A. Holmes in charge; F. M. Stanton, chemist.

Analyses of coal samples from Johnstown quadrangle, Pennsylvania—Continued.

	Lower Kittanning (B)—Continued.									
	11.	12.	13.	14.	15.	16.	17.	18.	19.	20.
Air-dried sample:										
Prox. Moisture	0.91	0.64	0.93	0.69	0.62	0.65	0.64	0.71	0.64	0.58
Prox. Volatile matter	15.93	14.67	14.94	15.36	14.55	15.95	18.21	18.14	18.35	18.09
Prox. Fixed carbon	75.39	76.38	77.22	74.06	79.43	79.65	74.74	74.77	72.67	74.72
Prox. Ash	7.77	8.31	6.91	9.89	5.40	3.75	6.41	6.38	8.34	6.61
Ult. Sulphur	1.97	2.29	1.36	4.55	.48	.78	1.52	1.92	2.81	1.42
Ult. Hydrogen	......	4.04	......	4.08	......	......	......	......	......	......
Ult. Carbon	......	81.10	......	77.95	......	......	......	......	......	......
Ult. Nitrogen	......	1.27	......	1.43	......	......	......	......	......	......
Ult. Oxygen	......	2.99	......	2.10	......	......	......	......	......	......
Calorific value determined:										
Calories	......	7,934	......	7,697	......	......	......	......	......	......
British thermal units	......	14,281	......	13,854	......	......	......	......	......	......

	Lower Kittanning (B)—Continued.							
	21.	22.	23.	24.	25.	26.	27.	28.
Sample as received:								
Prox. Moisture	2.80	3.45	2.59	3.83	2.84	3.13	2.57	3.49
Prox. Volatile matter	17.30	18.82	18.91	19.03	17.47	17.61	18.09	16.12
Prox. Fixed carbon	73.28	71.18	70.33	67.89	71.42	69.45	69.01	74.68
Prox. Ash	6.62	6.55	8.17	9.25	8.27	9.81	10.33	5.71
Ult. Sulphur	2.46	2.01	4.04	4.57	3.11	3.77	3.97	.95
Ult. Hydrogen	......	......	......	......	......	4.62	4.43	......
Ult. Carbon	......	......	......	......	......	76.41	75.89	......
Ult. Nitrogen	......	......	......	......	......	1.14	1.16	......
Ult. Oxygen	......	......	......	......	......	4.25	4.22	......
Calorific value determined—								
Calories	......	......	......	......	7,821	7,664	7,618	......
British thermal units	......	......	......	......	14,079	13,795	13,712	......
Loss of moisture on air drying	2.00	3.00	2.00	3.30	2.40	2.80	2.10	2.80
Air-dried sample:								
Prox. Moisture	.82	.46	.60	.55	.45	.34	.48	.71
Prox. Volatile matter	17.65	19.40	19.30	19.68	17.90	18.12	18.48	16.58
Prox. Fixed carbon	74.77	73.38	71.77	70.20	73.18	71.45	70.49	76.83
Prox. Ash	6.76	6.76	8.33	9.57	8.47	10.09	10.55	5.88
Ult. Sulphur	2.51	2.07	4.12	4.73	3.19	3.88	4.06	.98
Ult. Hydrogen	......	......	......	......	......	4.43	4.29	......
Ult. Carbon	......	......	......	......	......	78.61	77.52	......
Ult. Nitrogen	......	......	......	......	......	1.17	1.18	......
Ult. Oxygen	......	......	......	......	......	1.82	2.40	......
Calorific value determined—								
Calories	......	......	......	......	8,013	7,885	7,781	......
British thermal units	......	......	......	......	14,423	14,193	14,006	......

	Lower Kittanning (B)—Continued.							Brookville. (A).
	29.	30.	31.	32.	33.	34.	35.	36.
Sample as received:								
Prox. Moisture	3.09	2.31	1.10	0.59	2.80	2.48	4.00	2.35
Prox. Volatile matter	16.66	13.99	15.80	16.61	17.92	17.87	15.89	14.30
Prox. Fixed carbon	74.79	76.69	75.69	76.76	71.32	70.41	69.57	71.40
Prox. Ash	5.46	7.01	7.41	6.04	7.96	9.24	10.54	11.95
Ult. Sulphur	1.18	1.19	1.49	.91	2.29	3.03	2.85	3.30
Ult. Hydrogen	......	......	......	......	......	......	......	4.22
Ult. Carbon	......	......	......	......	......	......	......	75.16
Ult. Nitrogen	......	......	......	......	......	......	......	1.13
Ult. Oxygen	......	......	......	......	......	......	......	4.24
Calorific value determined—								
Calories	......	......	......	......	......	7,679	7,415	7,382
British thermal units	......	......	......	......	......	13,822	13,347	13,288
Loss of moisture on air drying	2.20	1.60	......	......	2.30	2.00	3.60	1.80

Analyses of coal samples from Johnstown quadrangle, Pennsylvania—Continued.

	Lower Kittanning (B)—Continued.							Brookville (A).
	29.	30.	31.	32.	33.	34.	35.	36.
Air-dried sample:								
Prox. Moisture	0.91	0.72	......	......	0.51	0.49	0.42	0.56
Prox. Volatile matter	17.03	14.22	......	......	18.34	18.23	16.48	14.56
Prox. Fixed carbon	76.47	77.94	......	......	73.00	71.85	72.17	72.71
Prox. Ash	5.59	7.12	......	......	8.15	9.43	10.93	12.17
Ult. Sulphur	1.21	1.21	......	......	2.34	3.09	2.96	3.36
Ult. Hydrogen	......	......	......	......	......	......	......	4.09
Ult. Carbon	......	......	......	......	......	......	......	76.53
Ult. Nitrogen	......	......	......	......	......	......	......	1.15
Ult. Oxygen	......	......	......	......	......	......	......	2.71
Calorific value determined—								
Calories	......	......	......	......	......	7,836	7,692	7,517
British thermal units	......	......	......	......	......	14,105	13,846	13,532

1. Conemaugh slope.
2. Johnstown.
3. South Fork.
4. Stony Creek, near trolley bridge between Moxhom and Ferndale, south of Johnstown.
5. South Fork.
6. Franklin.
7. Dale.
8. Johnstown.
9. Moxhom.
10. Solomons Run, southeast of Johnstown.
11. Franklin.
12. Johnstown.
13. Near Walsall.
14. Stony Creek, Somerset County, south of quadrangle.
15, 16. South Fork.
17, 18. Nanty Glo.
19. Vintondale.
20. Twin Rocks.
21. Near Weber Station, Blacklick Creek.
22. Twin Rocks.
23. Wehrum.
24, 25. Wehrum. Mine samples; see Bull. U. S. Geol. Survey No. 332, 1908, p. 201.
26, 27. Wehrum. Car samples; see Bull. U. S. Geol. Survey No. 332, 1908, p. 201.
28, 29. Ehrenfeld. J. S. Burrows, collector; see Bull. U. S. Geol. Survey No. 290, 1906, p. 179.
30. Scalp Level.
31, 32. Windber. Carload shipped by operators from Eureka No. 31 mine to St. Louis; see Bull. U. S. Geol. Survey No. 261, 1905, p. 51. Eureka No. 31 mine is not in the Johnstown quadrangle, and the correlation of the coal bed where the sample was procured is left open.
33, 34. Near Conemaugh Furnace. Mine samples; see Bull. U. S. Geol. Survey No. 332, 1908, p. 216.
35. Near Conemaugh Furnace. Car samples; see Bull. U. S. Geol. Survey No. 332, 1908, p. 216.
36. South Fork.

DESCRIPTION BY DISTRICTS.

For convenience in reference and from the commercial point of view the coal resources of the Johnstown quadrangle are described by districts, as follows: Johnstown district, South Fork-Mineral Point district, Blacklick Creek district, Windber district, and Conemaugh Furnace district. The territory included in these different districts will be outlined in the descriptions.

JOHNSTOWN DISTRICT.

EXTENT.

The Johnstown district includes the territory about the city of Johnstown and its suburbs; the hills along the valley of Conemaugh River, extending from East Conemaugh and Clapboard Run on the east to Laurel Run and the base of Laurel Ridge on the west; the region along Stony Creek and its tributaries, Solomons Run, Sams Run, and Bens Creek; and a few smaller areas back in the country and away from the channels of transportation.

CONEMAUGH COALS.

CHARACTER AND DISTRIBUTION.

The Conemaugh formation outcrops in all the hills in the immediate vicinity of Johnstown. In a section of 300 feet of this formation measured by John Fulton[a] above the Upper Freeport coal at Prossers Knob, near the city, but 3 inches of coal was detected about 65 feet above the Upper Freeport coal. A section was measured on the hill above the plant of the Johnstown Pressed Brick Company in which 400 feet of beds with concealed intervals were observed (see pp. 115–116), and no bed of coal was detected or reported as of workable thickness. It is probable, therefore, that in the Johnstown district the Conemaugh formation contains no bed of coal which under present conditions is of commercial importance.

GALLITZIN COAL.

In the vicinity of Johnstown the Gallitzin coal averages about 100 feet above the Upper Freeport coal. Some of the diamond-drill records obtained in the hills east of the city note a coal 1 foot in thickness slightly more than 100 feet above the Upper Freeport. The maximum thickness of this bed appears to be less than 2 feet and it is in places less than 1 foot thick. In some of the sections a coal appears as low as 70 feet above the Upper Freeport. Where there is but a single coal in the lower 110 feet of the Conemaugh it is difficult to decide whether it is the representative of the Gallitzin or of the next lower bed, the Mahoning coal. What is believed to be the equivalent of the Gallitzin has been noted well up on South Fork of Bens Creek, also on the west side of the hill south of Kring and west of Ingleside, and there is evidence that it has been prospected in both these localities. Its position was located on the Johnstown-Geistown road, along the trolley line south of Island Park. Where measured along the roadside it is very thin. It may be said that its occurrence in the Johnstown Basin is fairly widespread but that it is too thin to be classed among the future workable beds in this part of the quadrangle.

MAHONING COAL.

The Mahoning coal occurs very close to and above the Johnstown ore bed and between 50 and 55 feet above the Upper Freeport coal in the region near Johnstown. It consists where seen to best advantage of two benches, as shown in the following section measured above the Baltimore and Ohio Railroad tunnel on Stony Creek south of Johnstown:

[a] See pp. 17-18, this bulletin; also Second Geol. Survey Pennsylvania, vol. H2, 1877, p. 97.

Section of Mahoning coal south of Johnstown.

	Ft.	in.
Shale roof.		
Coal		5
Shale, drab, fossiliferous	2	0
Coal		6
Fire clay, dark.		

It is nowhere worked, so far as known, and it can not be considered among the future workable coals of the area.

ALLEGHENY COALS.

GEOLOGIC POSITION.

Four coals of workable thickness occur in the Allegheny formation in the Johnstown district—the Upper Freeport or Coke Yard bed, the Lower Freeport or Limestone bed, the Upper Kittanning or Cement bed, and the Lower Kittanning or Miller bed. These are also known by letters as the E, D, C′, and B coals, respectively. The Middle Kittanning also occurs, but so far as known is of workable thickness at only a few points and therefore can not be classed among the commercial coals of the district. All the coals except the Lower Kittanning lie at convenient intervals above drainage level in the hills immediately surrounding Johnstown and are extensively worked.

The entire Allegheny formation is exposed in the Johnstown district. Several sections obtained at widely scattered points serve well to illustrate the variations in the character of its rocks as well as the intervals which separate the coals. The sections were measured by hand leveling and by rule. Some of them are as follows:

(1) *Section of upper part of Allegheny formation near Valley Coal and Stone Company's mine, on Stony Creek.*

	Ft.	in.
Coal, Upper Freeport (E or Coke Yard coal)	3	3
Shale	14	
Shales, dark, concretionary	10	
Shales, blue	25	
Sandstone, laminated	5	
Shales and sandy shales	10	
Lower Freeport (D or Limestone coal): Coal, 1 foot; Bone, 1½ inches; Coal, 1 foot 7 inches; Bone, 1 inch; Coal, 3½ inches	3	1
Limestone	2	6
Shale and sandstone	8	
Shale, blue	15	
Coal, Upper Kittanning (Cement or C′ coal)	4 to 5	9 / 5
Shale	1	
Limestone	3½–4	
Shale, sandy, containing limestone concretions	8–10	
Sandstone, massive.		

The interval between the Upper Freeport and Upper Kittanning coals in the above section is about 90 feet.

The section is carried still lower by one measured south of the tunnel on the Baltimore and Ohio Railroad, which shows the relative positions of two small beds occurring between the Upper Kittanning or Cement bed and the Lower Kittanning or Miller bed. This section is as follows:

(2) *Section of Upper Kittanning coal and underlying coals south of tunnel on Baltimore and Ohio Railroad.*

	Ft.	In.
Coal, Upper Kittanning (Cement or C′ bed)	5	2
Shale		8–12
Limestone	6	
Shales, gray, concretionary	4–5	
Shale, drab, containing abundant ferruginous limestone concretions	6	
Shale, black		12–14
Coal		1½
Shale, blue, with ferruginous limestone concretions	6	
Shale, sandy	6	10
Coal		7½

The intervals between the three main coals in the upper part of the Allegheny formation, as well as the character of the intermediate rocks, are given in the following section obtained in the ventilating shaft of the Rolling Mill mine of the Cambria Steel Company on Mill Creek:

(3) *Section of upper part of Allegheny formation on Mill Creek.*

	Feet.
Upper Freeport coal.	
Concealed	20
Concealed by mine timber	22
Shale, hard	6
Sandstone	4
Shale	3½
Coal, Lower Freeport (Limestone or D coal)	1½
Limestone, nodular	2
Shale, dense, drab, or clay	10
Shale, blue, irregularly bedded	4
Shale, light drab	7
Sandstone	3
Shale	3
Shale, sandy	8
Top of Cement coal.	

The interval between the Upper Freeport and Upper Kittanning coals here is between 90 and 95 feet.

The following section was measured by F. B. Peck and W. C. Phalen on the Eighth Ward road, south of Kernville:

(4) *Section of upper part of Allegheny formation on Eighth Ward road, south of Kernville.*

	Ft.	In.
Coal, 3 feet 8 inches; Clay, 4 inches; Coal, 3 inches — Main Upper Freeport (Coke Yard or E coal).	4	3
Clay	2	6
Coal		3
Shale	5	
Shales, ferruginous	10	
Sandstone, argillaceous	8	
Sandstone, concretionary	3	
Sandstone, massive	19	
Shale, black	3	
Sandstone		4
Shale, black		3
Coal, 7–8 inches; Bone, ½–1 inch; Coal, 8 inches; Shale, black, 2 inches; Coal, 2 feet 6 inches — Lower Freeport (Limestone or D bed)	4	1
Shale, black		6
Limestone	3	9
Shale, blue	5	
Shale, massive, drab, ferruginous	7	
Shale, sandy	8	6
Shale, blue-black	4	
Coal, Upper Kittanning (Cement or C′ bed)	3	9
Shale	1	
Limestone	5	
Shale	3	6
Shale, sandy	5	
Shale, black and brown	3	
Coal	1	
Shales, sandy	5	
Shales	20	
Coal		11
Shales	25	

The interval here between the Upper Freeport and the Upper Kittanning coals is about 85 feet.

The following section is of interest, as it shows a coal between the Lower Freeport and Upper Kittanning beds, presumably the same bed as that above the Upper Kittanning at the mouth of the Rolling Mill mine and on Dalton Run.

(5) *Section of upper part of Allegheny formation south of stone bridge on Stony Creek, Johnstown.*

	Ft.	In.
Coal, 6 inches; Bone, 1 inch; Coal, 6½ inches; Shale, 1 inch; Coal, 1 foot 7 inches — Lower Freeport (Limestone or D coal)	2	9½
Fire clay	1	
Shale	3	

	Ft.	in.
Limestone	2	6
Shales	17–18	
Coal		8
Bone		9
Shales, brown, with concretions	3	6
Shale, sandy	8	4
Top of cement coal.		

The following section was measured in a small gully on the main line of the Pennsylvania Railroad half a mile east of Conemaugh depot.

(6) *Section of upper part of Allegheny formation on Pennsylvania Railroad east of East Conemaugh.*

	Ft.	in.
Coal, 3 feet 3 inches; Bone, 2 inches; Coal, $4\frac{1}{2}$ inches — Upper Freeport (Coke Yard or E coal)	3	$9\frac{1}{2}$
Shales	18	
Shale and sandstone beds	12	
Shales	4	10
Coal		8
Fire clay	4	
Limestone, green sandy		6
Sandstone, laminated	6	
Sandstone, shaly	5	
Sandstone, massive	40	
Coal, Upper Kittanning (Cement or C′ coal)	2	$11\frac{1}{2}$
Limestone	2	
Shale, gray, with limestone nodules	1	6
Limestone	5	
Shale, gray, with ferruginous concretions	5	
Shales, blue	17	
Railroad level.		
Shale, blue, with ferruginous limestone concretions	10	
Limestone nodules, blue, to creek level.		

The above section was completed down to the Lower Kittanning coal by a section a short distance to the west. Part of it could not be hand leveled but had to be measured by barometer. The section is as follows:

(7) *Section between Upper Kittanning (C′) and Lower Kittanning (B) coals.*

	Ft.	in.
Base of Upper Kittanning (C′ or Cement coal).		
Shales, bluish and gray (containing a small coal locally), with concretions; 40 feet of these shales are represented in the preceding section	50	
Coal		$10\frac{1}{2}$
Shales, greenish blue	6	8
Sandstone, gray	1	9
Shale, black	1	5
Sandstone, blue, thick bedded	5	8
Approximate interval made up chiefly of sandstone to Lower Kittanning (Miller or B bed)	25±	

The above sections well illustrate the character of the Allegheny rocks between the Lower Kittanning (Miller) coal and the Upper Freeport (Coke Yard) bed. The opportunities for measuring the interval from the Lower Kittanning to the top of the Pottsville are rare near Johnstown. On Clapboard Run this interval is about 70 feet. On Stony Creek south of the area the character of the rocks making up the interval was carefully determined and the section hand leveled. This section of the lower Allegheny is as follows:

(8) *Section from top of Pottsville to Lower Kittanning (Miller or B coal) on Stony Creek, south of Johnstown quadrangle.*

		Ft.	in.
Coal, 3 feet 8½ inches; Bone or black shale, 3½ inches; Coal, 3½ inches; Bone, 1 inch; Coal, 10 inches	Lower Kittanning (Miller or B coal)	5	2½
Fire clay		4	8
Sandstone, gray, laminated		9	8
Sandstone, massive		40	
Shale		2	
Coal and bone		3	7
Shale		10	
Sandstone, laminated		5	
Top of Pottsville.			

The interval from the base of the Lower Kittanning coal to the top of the Pottsville here is about 75 feet, which is very close to the interval of 70 feet measured on Clapboard Run.

In this section but one coal appears between the top of the Pottsville and the base of the Lower Kittanning (Miller) bed, but in places two coals occur in this interval, as in the section of the lower Allegheny rocks obtained near the brick plant of A. J. Haws & Sons (Limited), west of Coopersdale. (See p. 24, fig. 2, section A.)

Many other measurements of the intervals between the coals of the Allegheny were obtained in and near Johnstown. (See fig. 2.) These intervals and those brought out in the sections given above will be described in detail in considering the stratigraphy of the individual coal beds.

UPPER FREEPORT COAL.

Name and position.—In the Johnstown district the Upper Freeport or top coal of the Allegheny formation is commonly known as the Coke Yard coal, from the fact that it was coked in the early days of the iron industry at the old Cambria furnace on Laurel Run. It is also frequently referred to as the E coal. It lies at the top, indeed marks the top, of the Allegheny formation, being separated from the usually massive Mahoning sandstone member (of the Conemaugh formation) above by a few feet of shales, and being located between 255 and 265 feet above the top of the Pottsville formation, or "Conglomer-

A. EXPOSURE OF UPPER KITTANNING COAL AND JOHNSTOWN LIMESTONE MEMBER ("CEMENT BED" IN THE ILLUSTRATION) ON STONY CREEK, NEAR MINE OF VALLEY COAL AND STONE COMPANY.

B. UPPER FREEPORT COAL WITH OVERLYING SHALES AND BASE OF MAHONING SANDSTONE AT SOUTH PORTAL OF BALTIMORE AND OHIO RAILROAD TUNNEL, STONY CREEK.

ate Rock," as it is popularly known. Its relation to the other coals in the Allegheny formation are shown in figure 2 and may be learned from most of the sections just given (pp. 44–47).

Extent and development.—The Upper Freeport is present in all the hills along Conemaugh River near the city and its suburbs, extending as far to the west as the hills bordering east of Laurel Run. It is also above drainage level on Clapboard, Hinckston, and St. Clair runs and practically along the entire course of Stony Creek and its tributaries, Solomons and Sams runs. It is not above drainage level through the entire course of Bens Creek in this area, as the synclinal trough in Somerset County causes its disappearance for a short distance, but even there it is not deeply buried. Plate I gives an excellent idea of its outcrop in the vicinity of Johnstown.

Wherever the coal is exposed it has been worked fairly extensively, and it is now being worked on a large scale in many mines about Johnstown. The most important workings are those of the Cambria Steel Company at the Conemaugh slope. The Ferndale Coal Company also operates on an extensive scale. Many smaller mines on this coal bed are worked the year round, and many small banks, from which coal is never shipped by rail, are worked only during the winter season. The most important mines on this coal are indicated on Plate I.

Chemical character.—The composition of the Upper Freeport coal in the Johnstown district is shown in analyses 1 and 2, on page 40. These analyses indicate this coal to be a high-carbon coal with comparatively low moisture. The ash and the sulphur are high.

Occurrence and physical character.—Average and typical sections of the Upper Freeport coal in the Johnstown district are shown in figure 4. The main bench averages between 3 feet and 3 feet 10 inches in thickness, more nearly the former than the latter. In places there is present a lower bench, which only exceptionally (as at the mine of Lewis Eppley, on Hinckston Run) exceeds 4 or 5 inches in thickness. This lower bench is separated from the main bench by a thin bone or shale parting rarely more than 5 or 6 inches thick. The lower part of the coal bed is in some places so intimate a mixture of coal and bone that it is difficult to differentiate the two. Such is the case in section 19, obtained at the south portal of the tunnel of the Baltimore and Ohio Railroad on Stony Creek. (See Pl. VII, *B*.) At a bank on Bens Creek the coal shows a section (No. 21) quite different from the usual one, but this section was obtained at a point several miles away from most of the other sections, and the lack of measurements in the intermediate territory makes it impossible to state whether the thinning shown is local or general to the west of the Johnstown Basin. However, to the north of this point, on St. Clair

Run, the section seems to be as usual. Only the main bench of this coal is ever worked, and all the coal below the main bench serves as a floor, except where it is necessary to remove it for head room.

As a rule no partings were noted in the main bench of this coal in the Johnstown district, a particular in which it differs markedly from the equivalent bed about South Fork and along the southeastern flank of the Wilmore Basin. Its maximum thickness nowhere exceeds 5 feet and usually ranges near 4 feet. The minimum thickness may

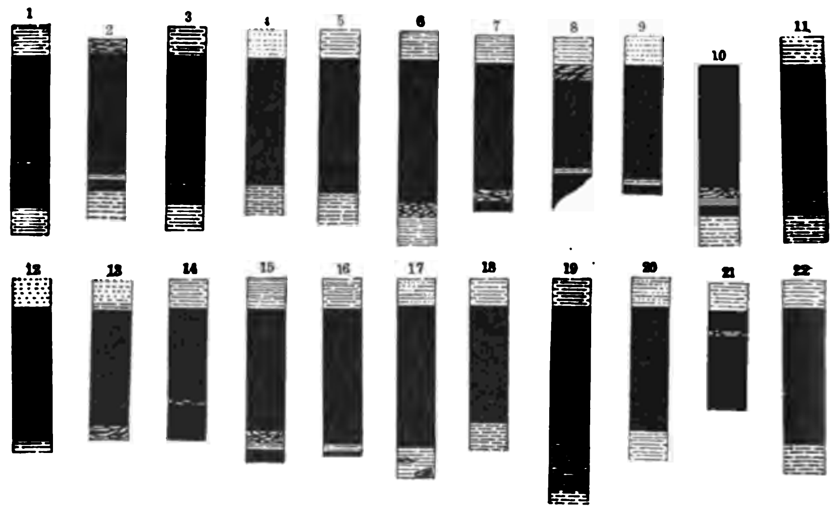

FIGURE 4.—Sections of the Upper Freeport (E or Coke Yard) coal in the Johnstown district. Scale, 1 inch = 5 feet.

1. Lewis Eppley, Hinckston Run, above Rosedale.
2. Conemaugh slope, Cambria Steel Company, west of East Conemaugh.
3. Country bank in ravine, north of Pennsylvania Railroad, northeast of East Conemaugh.
4. L. J. Mitchell, mouth of Clapboard Run.
5. Charles Umbarger, head of Clapboard Run.
6. Johnstown Pressed Brick Company, Frankstown road.
7. William Davis, Frankstown road.
8. William Schaeffer, Shingle Run, Dale.
9, 10, 11, 12. Berkebile Coal Company, Dale, north of Moxhom.
13. Country bank, Sams Run, just above Highland Coal and Coke Company's mine.
14. Ferndale Coal Company, Grubtown opening
15. Ferndale Coal Company.
16. Country bank, Roxbury.
17. Natural exposure along trolley line, opposite Valley Coal and Stone Company's mine.
18. Natural exposure along trolley line, south of Island Park.
19. South portal of Baltimore and Ohio Railroad tunnel, south of Johnstown.
20. Natural exposure on Stony Creek near mine of Valley Coal and Stone Company.
21. Bens Creek, Somerset County.
22. Country bank, St. Clair Run.

be regarded as 2 feet, though, as in all coal beds, local rolls pinch the coal out altogether. Such rolls, however, appear to be extremely rare in this coal bed, which is characterized by marked uniformity. There are few or no clay veins. The roof is usually shale or shaly sandstone, in places bony. It is generally firm, but draw slate is occasionally reported. In some of the mines great care is taken in propping to prevent falls.

LOWER FREEPORT COAL.

Name and position.—The next lower coal of importance in the Allegheny formation in the Johnstown district is the Lower Freeport or D coal. It is popularly known as the Limestone coal, and is better known about Johnstown under this name than under either of the other two.

It lies from 50 to 65 feet below the Upper Freeport (Coke Yard) coal and from 25 to 36 feet above the Upper Kittanning (Cement) coal in the valley of Stony Creek, both south and west of Johnstown. On Mill Creek it is 55 feet below the Upper Freeport coal and about 37 feet above the Upper Kittanning coal. On Peggys Run, near the Franklin mine of the Cambria Steel Company, it is 58 feet below the Upper Freeport and 45 feet above the Upper Kittanning, which is here worked. In section 6, page 47, the 8-inch coal 35 feet below the Upper Freeport coal may not be the representative of the Lower Freeport; certainly its distance below the Upper Freeport is very much less than that usual in the district as a whole.

Extent and development.—The Lower Freeport coal is above drainage level, as is the Upper Freeport bed, in all the hills near Johnstown, outcropping along Conemaugh River, Stony Creek, and their tributaries. Its outcrop line, if drawn on the map (Pl. I), would fall between that of the Upper Freeport and Upper Kittanning coals.

The coal has been prospected at many points about the city and its suburbs, but it is not mined, at least on a commercial scale, at the present time. The most promising outcrops were observed along Stony Creek from the vicinity of the mines of the Valley Coal and Stone Company northward to Roxbury. On Peggys Run, near Franklin, it was prospected and proved to be 4 feet thick but so badly broken by partings that it is not commercially valuable. It is reported 18 inches thick with a shale band in the middle in the hills north of Coopersdale. It is believed to be one of the important coals of the future in this district, especially along Stony Creek.

Chemical character.—In the sample of coal collected south of Johnstown, the analysis of which is given on page 40 (No. 4), the clay partings were not included, as these will be discarded when the coal is worked on a commercial scale.

In the analysis the percentage of carbon is high and comparable with this constituent in other coals in this district. The moisture can not be considered representative, as the sample was procured near the outcrop. The ash runs rather high but not above the average of the coals of the area. The coal from this bed is not considered good in the region about Johnstown, but the analysis of the sample collected near Stony Creek (see p. 40) indicates that in this locality, where the coal is persistent and of workable thickness, it has commercial importance.

Occurrence and physical character.—The Lower Freeport coal occurs as a rule in three distinct benches (see fig. 5) in the territory about Johnstown and from Ferndale southward on Stony Creek. These benches are separated by thin shale or bone partings. The top bench averages about a foot in thickness and the middle bench about 2 feet. In the commercial development of this coal bed only these two benches will be worked, the underlying coal and bone serving as a floor. It may be said, therefore, that in this locality there is present from 2½ to 3 feet of coal. Southeast of Johnstown, at Dale and on Sams and Solomons runs, where this coal was measured by F. B. Peck and Lawrence Martin, a thin bench, usually under 6 inches, occurs at the top of the bed, and the two main benches are below, separated by bone or shale. In this part of the district these two workable benches do not average as much coal as in the workable parts of the bed on Stony Creek.

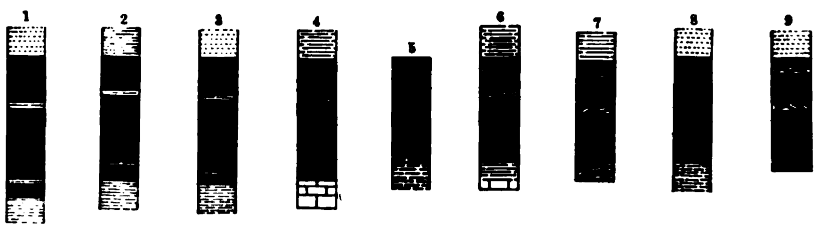

FIGURE 5.—Sections of the Lower Freeport (D or Limestone) coal in the Johnstown district. Scale, 1 inch=5 feet.

1. Natural exposure south of Kernville, near Citizens Eighth Ward mine.
2. Exposure on Baltimore and Ohio Railroad, west bank of Stony Creek, opposite Lorraine Steel Company's plant.
3. Stony Creek near trolley bridge.
4. Stony Creek near Valley Coal and Stone Company's mine.
5. West bank of Stony Creek, Johnstown.
6. Sams Run.
7. Dale.
8, 9. Head of Solomons Run.

Immediately over the coal are usually a few inches of bone and black shale overlain by dense shale, sandy shale, or massive sandstone. Plate IV, *A* (p. 24), gives an idea of the character of this roof. The coal is underlain by clay, below which occurs the limestone, though in places the limestone underlies the coal directly.

UPPER KITTANNING COAL.

Name and position.—The next lower coal of importance in this district is the Upper Kittanning coal. It is also referred to as the C′ coal, but more commonly is known as the Cement seam, from the bed of cement rock which closely underlies it. In the early reports of the Second Geological Survey of Pennsylvania it was called the Lower Freeport or D coal and the coal next above it was referred to as the Middle Freeport or D′ bed.[a]

[a] Second Geol. Survey Pennsylvania. Rept. H2, 1877, p. xxviii.

The Upper Kittanning coal commonly occurs within 100 feet of the Upper Freeport (Coke Yard) bed. At Kernville the interval between the two is about 90 feet; on Stony Creek near the Valley Coal and Stone Company's mine it is 90 feet; on Mill Creek, between 90 and 95 feet; south of Kernville, on the trolley line, 84 feet. On the Frankstown road an interval of about 100 feet was measured, though it was reported that the two coals locally occur as near to each other as 80 feet. Along the main line of the Pennsylvania Railroad just east of Conemaugh depot the interval is 90 feet, and near the Franklin mines it was reported as 103 feet. It can be stated, therefore, that about 95 feet below the Upper Freeport (Coke Yard) coal the prospector may expect to find the representative of the Upper Kittanning (Cement) coal in the Johnstown district. Sections 1, 3, 4, and 6, on pages 44 to 47, and the compiled sections obtained near Coopersdale and on Clapboard and Peggys runs (fig. 2) clearly indicate its relation to all the coals in this district.

Extent and development.—The Upper Kittanning (Cement) seam outcrops at a height above drainage level that is convenient for exploitation at practically all points about Johnstown. West of the city and north of Conemaugh River the coal is worked on the estate of Lewis J. Prosser, at the north end of Ten Acre Bridge. Here the coal is just below the flood-plain level at the base of the hill and has to be reached by slopes. A short distance to the west, just back of Coopersdale, a slight rise in the beds brings this coal above the flood plain, and a few abandoned banks indicate that it was formerly worked on a small scale here. The steep rise in the formations toward the west does not allow it to appear in the hills west of Laurel Run. To the east of the synclinal axis along Hinckston Run the coal is above drainage level and was worked just above the present location of Johnstown depot. Though not now exposed at that exact point, the fairly massive sandstone which usually overlies it is well exposed near the position of the old Ray furnace. A very short distance to the east the coal appears in the cliffs bordering the railroad, and it may be traced beyond Conemaugh depot. At present there are no workings of note on it east of Johnstown depot and north of the Little Conemaugh, though, as will be seen from section 6, page 47, it is 3 feet thick and hence workable in this general locality.

South of Conemaugh River, well up toward the head of Clapboard Run, the coal is worked in a small way at the present time. It is 2 feet 10 inches thick at the mine of Harry Wissinger, and this indicates that its thickness south of the river is much the same as that to the north, near Conemaugh depot. A few old openings on the bed were also noticed near the mouth of Clapboard Run. On Peggys Run is located Franklin No. 1 mine of the Cambria Steel Company. In the eastern part of Johnstown, on the Frankstown road, the coal

workings of at least one of which extend
ut on the Dale road leading to Walnut
has been opened by numerous private
, and the workings extend eastward to
p to the head of Solomons Run. The
banks are shown on Plate I, and the char-
e outlined subsequently. (See pp. 54–56.)
and Moxhom and on Sams Run east of
thick (see sections 11, 12, and 13, below)
ighland Coal and Coke Company and the
y. Farther south, on Stony Creek, toward
kens from 3 or 4 feet to as much as 6 feet in
ie of the Valley Coal and Stone Company,
mines only about 5 feet. (See Pl. VII, *A*.)
nore and Ohio Railroad north of Kring 5 feet
easured. (See section 2, p. 45.) This thick
rd. The westward dips toward the Johns-
bed below drainage level less than a mile
imore and Ohio Railroad tunnel south of

and 2 miles southwest of Kring, on a creek
he Upper Kittanning (Cement) coal has been
Smokeless Coal Company. Here also more
as measured. Where observed along Bens
ty the bed is also of workable thickness. It
ie confluence of the north and south forks of
l of Elizabeth Cable, on Dalton Run, and at
alton Run. In this locality the small seam
ttanning was observed. In the region north
is 4 feet or more in thickness. Immediately
operations of the Cambria Steel Company
ward in Upper Yoder Township beyond Mill
shown no tendency to become too thin to
ll mine, in which these extensive operations
rgest mine in the area and indeed one of the

Cambria the Upper Kittanning (Cement) bed
and has been opened in many places. At the
W. Fuge the coal is about 3 feet in thickness.
rellville the coal has been mined and may be
ble thickness. It may be stated, therefore,
n the Upper Kittanning coal is workable.
Analyses 5 to 10, page 40, indicate the com-

high-carbon coal with correspondingly low
oisture is low, but ash and sulphur are high.

FIGURE 6.—Sections of the [illegible]

1. [illegible] Steel Company. Rollin
2. [illegible] north end Ten Acre
3. E. W. Fuge, Cambria.
4. [illegible] Fuge, Cambria.
5. 6. In cut on Baltimore and O
7. In cut on Baltimore and Ohi
8. Natural exposure, near V
9. Valley Coal and Stone
10. Kelso Smokeless Co
11. Highland Coal and
12. 13. Sunnyside Co
14. George Heilinger
15. D. D. Stoll, bed
16. Jacoby mine, e
17. Wertz & Miller
18. William Rob
19. Edward Li
20. Suppes Co
21. 22. Citizen
23. Caddy mi
24. Fyock's m
25. Jacoby m
26. Suppes C
27. Natural e
28. John F.
29. Head o
30. Camb
31. Dalto
32. Dalto
33. Willi

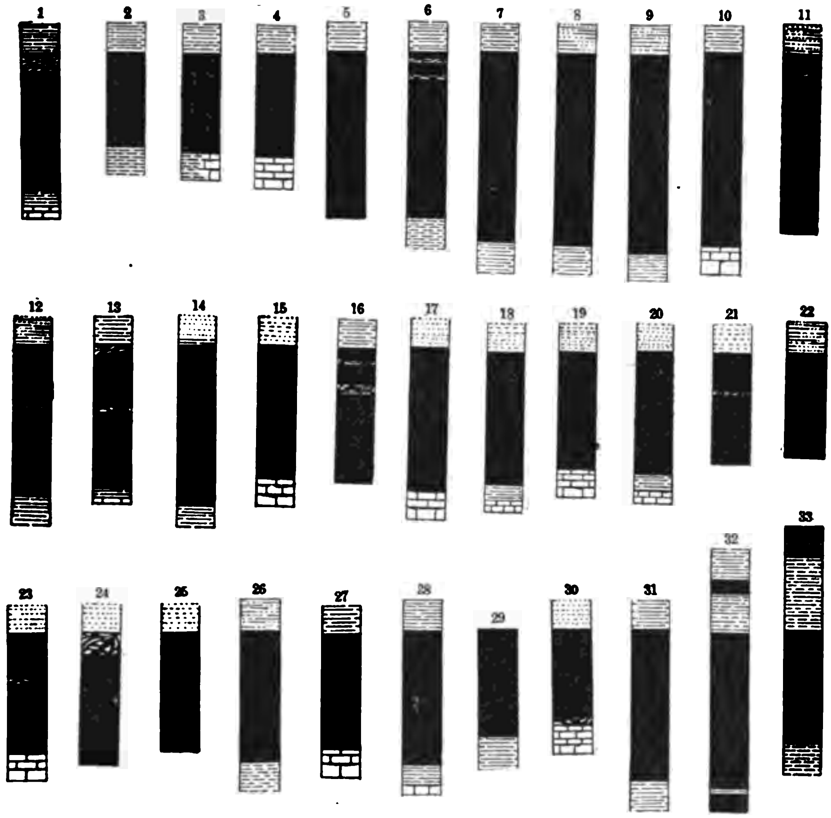

FIGURE 6.—Sections of the Upper Kittanning (C′ or Cement) coal in the Johnstown district.
Scale, 1 inch = 5 feet.

1. Cambria Steel Company, Rolling Mill mine.
2. L. Prosser, north end Ten Acre Bridge.
3. E. W. Fuge, Cambria.
4. Samuel Fuge, Cambria.
5, 6. In cut on Baltimore and Ohio Railroad, west side of Stony Creek, opposite Moxhom.
7. In cut on Baltimore and Ohio Railroad north of Kring.
8. Natural exposure, near Valley Coal and Stone Company's mine.
9. Valley Coal and Stone Company.
10. Kelso Smokeless Coal Company.
11. Highland Coal and Coke Company, Sams Run, east of Moxhom.
12, 13. Sunnyside Coal Company, between Dale and Moxhom.
14. George Heidingsfelder, head of Solomons Run.
15. D. D. Stoll, head of Solomons Run.
16. Jacoby mine, eastern part of Dale or Walnut Grove.
17. Wertz & Miller, Walnut Grove.
18. William Rohde, Solomons Run, east of Dale.
19. Edward Litzinger, Solomons Run, east of Dale.
20. Suppes Coal Company, Chas. H. Suppes, jr., Dale opening.
21, 22. Citizens' Coal Company, Dale mine.
23. Caddy mine.
24. Fyock's mine.
25. Jacoby mine (second opening), Dale.
26. Suppes Coal Company, Chas. H. Suppes, jr., Frankstown road opening to Dale mine. (See No. 20.)
27. Natural exposure, east of Johnstown.
28. John F. Griffith, Frankstown road, Johnstown.
29. Head of Clapboard Run.
30. Cambria Steel Company, Franklin No. 1.
31. Dalton Run, at the reservoir.
32. Dalton Run, Elizabeth Cable.
33. William McAuliff, Bens Creek, near confluence of North and South forks.

Occurrence and physical character.—West of Johnstown, at the Cambria openings south of Conemaugh River, and north of Conemaugh River, the Upper Kittanning coal averages very nearly 3 feet in thickness; at one opening, however, it was only 2 feet 7 inches as measured. To the south along Stony Creek the bed gradually grows thicker, as indicated in sections 5, 6, 7, 8, 9, and 10 (fig. 6). As much as 6 feet of coal was reported in places and several measurements of 5 feet were made. (See fig. 6.) The bony character of the upper 8 inches is indicated in section 6, and as a rule the upper 8 to 12 inches has to be discarded. On Sams Run, east of Moxhom, and between Dale and Moxhom, according to observations made by F. B. Peck, the coal is between 3½ and 4 feet thick, generally with a few inches of bone (discarded in mining) at the top and a small bony streak about midway between the roof and floor. At Dale and on Solomons Run the bed is usually made up of good solid coal, varying in thickness from nearly 3 feet to more than 4 feet, here and there with a bony streak near the middle and in many places with a few inches of bone at the top. On Peggys Run and in the exposures along the Pennsylvania Railroad the coal is not 3 feet thick and in places is less than 2½ feet thick. In Upper Yoder Township the coal ranges from 3 to 4 feet in thickness, often with one or two smaller coals above.

As a rule the coal of this bed is a good clean product, generally uniform throughout. In a few of the mines the upper foot of coal is reported soft and the lower foot harder than the average. The roof of the coal is either very dense shale or else sandy shale or sandstone and gives no trouble whatsoever. The floor is usually a few inches of firm shale or clay closely underlain by the Johnstown "cement" bed. This cement bed locally underlies the coal directly. (See Pl. VII, *A*.) The coal bed is uniform in thickness and few rolls are reported. Clay veins are, however, numerous and in places are very annoying. Considerable trouble is often caused by gas, which necessitates the use of safety lamps.

MIDDLE KITTANNING COAL.

In considering the stratigraphy of the different members of the Allegheny formation the presence of two small coals between the Upper and Lower Kittanning beds was pointed out (p. 26). The lower of these coals is regarded as the equivalent of the Middle Kittanning (C) coal in the Johnstown district. South of the tunnel on the Baltimore and Ohio Railroad going to Kring the distance from the base of the Upper Kittanning (Cement) bed to this coal is 32 feet (section 2, p. 45); the coal here is only 7½ inches thick. South of Kernville, near the Eighth Ward mine of the Citizens Coal Company, this coal is 11 inches thick and is about 43 feet below the base of the Upper Kittanning bed (section 4, p. 46). Along the Pennsylvania Railroad near Conemaugh depot the interval between the Cement bed and the Middle Kittanning coal is about the same—namely, 45 to 50 feet—but the coal here is only 10½ inches thick (section 7, p. 47). At these different places the Middle Kittanning coal is not of workable thickness, and as a rule it can not be considered workable in this district. It is fairly persistent, however, and hence serves as an additional check on the identity of the beds both above and below it. It has been opened at Coopersdale, at the brick plant of A. J. Haws & Sons (Limited), where it is about 25 feet above the Lower Kittanning coal and shows a thickness of 30 inches, with more concealed. It is also said to be of workable thickness at the head of Solomons Run. From what is known about it at present it can not be classed among the commercial coals of the district.

LOWER KITTANNING COAL.

Name and position.—The next lower important coal in the Allegheny formation is the Lower Kittanning coal. It is also known as the Miller or B bed in and near Johnstown. Its position below the Upper Kittanning (Cement) bed can be obtained by direct measurement at only a very few points in the Johnstown district, as most of the operations on it are conducted either by slope or incline. At the foot of the hill ascending from Kernville to Grandview Cemetery, Johnstown, the interval was reported to be 98 feet, and where hand leveled on Stony Creek south of the quadrangle it was just 100 feet. Near the Ingleside Coal Company's mine it was reported to be 86 feet. Near the Franklin mines of the Cambria Coal Company the interval between the Upper and Lower Kittanning beds was ascertained by means of a bore hole to be 90 feet. It may therefore be safely assumed that the Lower Kittanning will be found 85 to 100 feet below the Upper Kittanning (Cement) bed.

Extent and development.—Immediately about Johnstown the Lower Kittanning coal is near to or below drainage level and the mines working the coal are either slopes or shafts. North of Conemaugh River and just at the western edge of Coopersdale the rise of the measures approaching Laurel Ridge brings the coal above drainage, and it is worked by A. J. Haws & Sons (Limited) at their brick plant. The under clay is also mined in connection with the coal. To the north on Laurel Run the coal has been opened in a small way by John Adams. East of the Haws mine the coal disappears below drainage level and does not reappear until it reaches a point just east of Conemaugh depot, where it is worked by the Keystone Coal and Coke Company. From this point as far to the east as South Fork it is above drainage level throughout nearly the entire course of

Conemaugh River, varying of course in elevation above the river, owing to the Ebensburg anticline and the circuitous course of the stream.

South of Conemaugh River what is possibly the Lower Kittanning coal is worked at present by J. L. Custer well up on Clapboard Run. It has been worked near the mouth of the run by the Argyle Coal Company, but considerable difficulty was experienced owing to the irregularities in the bed, which ultimately led to the abandonment of operations. A short distance away, on Peggys Run, the Cambria Steel Company has opened its Franklin No. 2 mine. In this mine (No. 48, Pl. I) much difficulty has been experienced and much expensive dead work required owing to the irregularities in the coal. (See pp. 59, 60.) In the city of Johnstown the Citizens' Coal Company has a slope to this coal bed near the Adams Street Schoolhouse, and in Kernville the coal is worked by W. J. Williams. The coal is above drainage level for a short distance on Solomons Run, coming up just at the mouth of Falls Run. To the south along Stony Creek the coal appears above drainage level near Kring, and it is worked farther south on the east side of the creek by the Ingleside Coal Company. In the suburbs west of Johnstown—that is, at Morrellville and on St. Clair Run—the coal is worked by W. J. Williams and by Robertson & Griffith. Thus the total number of mines on this bed in this region is about ten.

Chemical character.—Analyses of this coal (Nos. 11 to 14, pp. 40–41) give an idea of its composition in the Johnstown Basin.

Like the coals already considered, the Lower Kittanning (Miller) coal in the Johnstown district is a high-carbon coal low in volatile matter and moisture. The ash and sulphur show considerable variation, but this may be accounted for partly by the fact that the samples were collected at scattered localities. The ash and sulphur seem to be much in excess of these constituents in coals from the South Fork district. As a steam coal the Lower Kittanning ranks very high; the engines on the Pennsylvania Railroad are supplied in part with it from one of the mines along the line. The coal is also coked at Franklin by the Cambria Steel Company in by-product ovens for use in the company's steel plant near Johnstown. It gives satisfactory results but has to be washed before coking, thereby adding to the cost of the product. Even with this additional item of cost it is found cheaper to coke this coal on the ground than to buy coke of better quality from the Connellsville region.

Occurrence and physical character.—The thickness of the Lower Kittanning (Miller) coal in the Johnstown district is shown in figure 7; it ranges from 3½ to 4 feet, the latter figure probably being a maximum for the Johnstown Basin. Except along Clapboard and Peggys runs and near Franklin, the coal is on the whole regular; its floor rolls and here and there the coal is cut down to 2 feet, but rarely to less than this. Clay veins are generally absent and where present are small. In and about Johnstown, less than a foot below the base of the main bench and separated from it by shale, there is commonly a small coal, which varies from 7 to 24 inches, the latter measurement being made at the mine of the Somerset and Cambria Coal Company's opening on Stony Creek, near Foustwell. Below the lower coal (or in its absence below the main bench) occurs a light to dark drab plastic clay, ranging from 3 to 6 feet in thickness. It was observed that where the clay was at a maximum the coal appeared in a single bench, with the lower part bony; but it can not be stated that this condition is the usual one. The clay is of great importance near Johnstown. (See pp. 117–118.) The coal itself is in general entirely

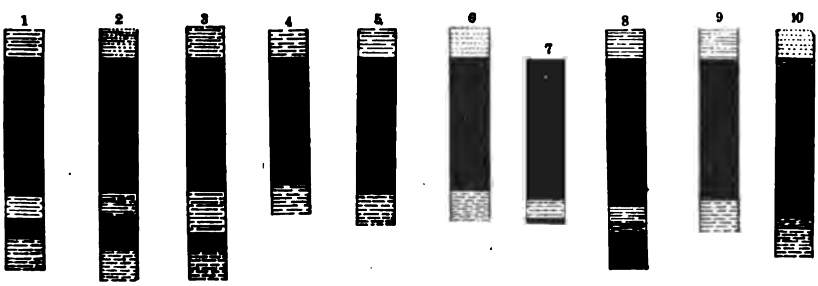

FIGURE 7.—Sections of the Lower Kittanning (Miller or B) coal in the Johnstown district. Scale, 1 inch = 5 feet.

1. John Adams, Laurel Run.
2. A. J. Haws & Sons, Coopersdale mine.
3. A. J. Haws & Sons, shaft at brick plant.
4. W. J. Williams, Kernville.
5. Citizens' Coal Company, Green Hill mine.
6. Cambria Steel Company, Franklin No. 2.
7. Cambria Steel Company, Franklin No. 2, outlet on Clapboard Run.
8. Keystone Coal and Coke Company, Conemaugh slope.
9. Ingleside Coal Company.
10. Robertson & Griffith, St. Clair Run.

free from partings and is uniform from roof to floor. The roof is massive sandstone, tough shale, or sandy shale, requiring little or no timbering, and there is no draw slate reported.

At Franklin and on Clapboard Run, on the other hand, the Lower Kittanning coal is erratic, and much difficulty has been experienced in mining on account of the irregular character of the floor. These irregularities are termed faults by the miners, but they are not faults in the geologic sense. The coal in this locality may be 6 feet thick in one place and only 15 inches thick a few feet away, and over small areas it is completely absent. It is believed that this singular occurrence is due to peculiar conditions of sedimentation during or subsequent to its original deposition in this locality, and not to subsequent movement, and that the trouble will be found to be only local and will disappear to the south. In confirmation of this belief may be cited two drill holes, one on the Frankstown road and the other near the head of Peggys Run, in which the Lower Kittanning coal is normally developed. So far as known, the coals above the Lower Kittanning (Miller) are normal in their occurrence; if the cause for the erratic conditions in the Lower Kittanning were regional, the Upper Kittanning (Cement) coal, which is worked at higher levels in the same hills, would probably be irregular likewise. The slight folds or rolls in the structure observed along the Pennsylvania Railroad near East Conemaugh are considered to have had nothing to do with the peculiar conditions just described. These irregularities have led to much expensive dead work near Franklin and have caused the abandonment of large operations on Clapboard Run.

LOWER ALLEGHENY COALS.

Coals lower than the Lower Kittanning and yet in the Allegheny formation are exposed in this district. At Coopersdale the top of the Pottsville formation appears at road level just west of the brick plant of A. J. Haws & Sons (Limited). Just above, two small coal beds, each measuring less than 2½ feet, are exposed, separated by about 10 feet of dark shale. The section is given on page 23. These coals probably correspond to the Brookville (A) and Clarion (A′) of the Allegheny Valley. One of these, probably the lower (Brookville), is exposed on Clapboard Run. The Lower Kittanning seam has been opened along this run, and about 70 feet below it a coal has been worked which is considered the Brookville or a coal very close to it. Two sections of this coal are as follows:

Sections of Brookville coal on Clapboard Run.

	Ft.	In.		Ft.	In.
Bony coal	1	8	Bone or shale		9
Bone		1	Coal		3
Coal	1	8	Bone		½
			Coal		6
			Bone or shale		1
			Coal	1	7

These sections are very similar, showing an upper bench from 18½ to 20 inches in thickness, mostly of bone and of no value, and a lower bench 19 or 20 inches thick. The coal has no value along this run.

South of the quadrangle, between the mouth of Paint Creek and Foustwell, the lower part of the Allegheny, together with the whole of the Pottsville and a large part of the Mauch Chunk formation, is brought above drainage level on the flanks of the Ebensburg or Viaduct anticline. The section on page 27 shows a coal 10 to 15 feet above the massive sandstone at the top of the Pottsville and separated from it by shale and sandstone. It is quite possible that this may be the Clarion coal. At least it is one of the Brookville-Clarion coal group. (See fig. 8.)

FIGURE 8.—Section of the Clarion (A′) coal along Baltimore and Ohio Railroad near southern edge of Johnstown quadrangle. Scale, 1 inch = 5 feet.

POTTSVILLE COALS.

The Pottsville formation lies below the Allegheny formation and, as indicated on page 28, consists of an upper and a lower sandstone member with an intervening shale member. This shale in many places carries a coal known as the Mercer. The coal appearing between the tipple of the Ingleside Coal Company and Kring, on Stony Creek south of Johnstown, is considered to belong in the Mercer coal group. The section is as follows (see also fig. 2):

Section of Mercer coal south of Kring.

	Ft.	In.
Black shale	5	6
Coal		9
Pyritiferous dark sandstone		1–2
Coal		6
Shale		2
Coal		9
Coal and bone		11
Black shale		3–4
Coal		4
Bone		4½
Clay	1	

The coal is so badly broken that it can not be considered among the workable beds of the district.

Near Sheridan the Mercer coal is about a foot thick. (See p. 119.)

SOUTH FORK-MINERAL POINT DISTRICT.

EXTENT.

In the South Fork-Mineral Point district will be included all the coal occurrences between, in, and near the two towns named. The mining operations extend from Ehrenfeld on the east to the point where Conemaugh River makes a sharp bend to the south, about 2 miles west of Mineral Point. Operations are conducted on both sides of the river. The openings are confined to the immediate river valley, but the workings in many of the larger mines are very extensive and have been pushed back into the hills a long distance from the river.

GEOLOGIC POSITION OF COALS.

The three formations which are of economic interest in the district are the Conemaugh, Allegheny, and Pottsville. The dips near South Fork are steep and the rock exposures are too imperfect to permit complete and detailed sections. North and south of Conemaugh River, however, diamond-drill holes have been put down and the records have apparently been carefully kept. Opportunity was afforded also for a measurement of the rocks in the shaft of the Pennsylvania, Beech Creek, and Eastern Coal Company near New Germany. A very clear idea, therefore, of the rocks as far down in the section as the Lower Kittanning (Miller) coal has been obtained.

On South Fork of Conemaugh River, near the northernmost cottage of the group near the old dam site, the interval between the Upper Freeport and Lower Kittanning coals is 206 feet. In the shaft at New Germany the interval between the two coals is 145 feet, a decrease to the north of 61 feet. It is known that this decrease in the interval takes place within a distance of 4½ miles, and it is possible that it may occur within a shorter distance.

CONEMAUGH COALS.

COAL NEAR SUMMERHILL.

Northwest of Summerhill, at an elevation of 1,800 feet, a coal has been opened by the side of the public road. It is reported to be exactly 300 feet above the Upper Freeport (Lemon or E) coal. The openings have entirely fallen in and no opportunity was afforded to measure the thickness or ascertain the character of the coal. The information was received that about 40 acres of territory had been worked out and that the coal was 4 feet thick. A measurement of the thickness of the part of the coal exposed along the roadside fully corroborates this information.

This occurrence is probably that described by Platt under the heading "Brown's mine, near Summerhill." Platt's description is as follows: [a]

> Northeast of the outcrop [of the E coal?] the hill rises steadily for 250 feet, and near the top Mr. Brown opened up a bed of coal unlike, both in character and in position geologically, any other coal thus far known in Cambria County. It overlies the Upper Freeport bed (E) certainly by as much as 200 feet; but the intervening measures are concealed, and their character is therefore almost wholly unknown.
>
> The bed has very little cover and is irregular and uneven, both roof and floor undergoing frequent changes, sometimes within a few yards. Moreover, the thickness of the bed has been very seriously affected by "horsebacks" and "clay veins," the coal varying in width all the way from 4 feet to as many inches.
>
> Two drifts were started in on the bed at the outcrop; one gangway is driven northwest and the other northeast. In both entries there is a sharp rise, that to the northeast being due to a local roll in the rocks of tolerably wide sweep.

[a] Second Geol. Survey Pennsylvania, Rept. H2, 1877, pp. 38-40.

The following measurements of the bed, made in the northeast gangway, will serve to give a clearer expression to the actual condition of things:

Section made near mouth of mine.

	Ft.	In.
Roof, "black slate"	1	
Coal, compact and of cuboidal structure	1	6
Coal, friable and of columnar structure		4
Coal, cuboidal structure	2	10
Floor, "slate," alternating with sandstone.		

Section made 60 feet beyond last.

	Ft.	In.
Sandstone.		
Slate		6
Coal	2	
Slate		2
Coal	1	3

Between these two measurements a "clay vein" intervenes, cutting out the coal almost entirely for a short distance. The bed then resumes its full height as given above, but diminishes steadily in going northeast, until at the end of the entry the coal is no longer of workable size, as follows:

	Ft.	In.
Roof, sandstone.		
Coal	1	6
Sandstone floor.		

At this point operations were brought to a close.

In the northwest mine the coal attains its greatest thickness, but is everywhere slaty and poor; it shows, however, throughout, the same horizontal crystallization already noted in connection with the other mine. The northwest entry was driven in several hundred yards, but with practically the same results as attended the operations elsewhere. These continued troubles naturally led to the abandonment of the mines.

The bed is represented only in the tops of the highest hills and covers a very limited area. The rise in the rocks carries it into the air a short distance west of Brown's openings, and east of the synclinal axis it is not known to occur.

Considering the geological horizon of the bed, together with the slaty character of the coal from it, it is apparent that this is one of the seams of the Barren Measures, of which there are several, usually thin and unimportant, but here, and confined perhaps to this immediate territory, of abnormal thickness and width.

The bed also undergoes such marked changes in point of character that no one specimen would fairly represent the average run of the mine. In the main, however, the coal is poor, being heavily loaded with earthy matter and other impurities. But along the center of the bed ranges not infrequently a narrow belt of soft, bright, rich clean coal, the limits of which are clearly defined both above and below by benches of smooth, tough, slaty coal. * * *

Two analyses of the coal were therefore made of specimens selected and forwarded to Harrisburg by the owners of the property, the Messrs. Brown, of Summerhill. The first analysis represents the small bench of soft friable coal, and reads as follows (D. McCreath):

Water at 225°	0.820
Volatile matter	19.155
Fixed carbon	70.175
Sulphur	.445
Ash	9.405
	100.000

Coke, per cent, 80.025; color of ash, gray. The coal is bright, tender, and seamed with charcoal and pyrites.

The other analysis may be said to represent the condition of the greater portion of the bed. The large percentage of ash, nearly one-fifth of the whole, gives to this coal its firmness and compactness and also its slightly conchoidal fracture and dull luster, but at the same time it ruins the bed totally for all practical purposes. The analysis also shows that this cannel slate is more sulphurous than the bench of soft coal in the center of the bed. The analysis is as follows (D. McCreath):

Water at 225°	0.550
Volatile matter	17.325
Fixed carbon	61.632
Sulphur	1.033
Ash	19.460
	100.000

Coke, per cent, 82.125; color of ash, gray. The coal is exceedingly compact, has a dull, resinous luster generally, but carries seams of bright crystalline coal.

GALLITZIN COAL.

South of South Fork a coal appears in the sections about 115 feet above the Upper Freeport (Lemon or E) bed. From its interval this is probably the representative of the Gallitzin bed. It is not workable, as it is rarely more than a foot thick. North of South Fork this coal is about 65 feet above the Upper Freeport coal. Another coal, possibly the Mahoning, appears below it in the section; this likewise is not workable near South Fork.

ALLEGHENY COALS.

Four coals have been worked in the Allegheny formation in the South Fork-Mineral Point district. They are (1) the Upper Freeport or E coal, which is known near South Fork and also along the eastern margin of the Wilmore Basin as the Lemon coal; (2) the Upper Kittanning or Cement coal; (3) the Lower Kittanning, Miller, or White Ash coal; and (4) the Brookville, usually referred to as the Dirty A coal. The first three are of greatest importance in this district.

UPPER FREEPORT COAL.

Name and position.—As stated above, the Upper Freeport coal is known at South Fork as the Lemon coal. It is also sometimes called the E bed, having been so termed by the geologists of the Second Geological Survey of Pennsylvania. It is also often referred to as the Four-foot coal. The position of this coal at the top of the Allegheny and its relations to the lower Allegheny coals are shown in figure 2. Its position with reference to the Mahoning sandstone in the South Fork district is indicated in the following section measured at Ehrenfeld:

Section of Upper Freeport (Lemon) coal and associated beds at Ehrenfeld, Pa.

	Ft.	In.
Shale	15	
Shale, olive and drab, locally sandy (Upper Mahoning?)	30	
Coal (Mahoning, upper bench)		4–5
Shale	8	
Shale, black		2
Shale, blue and black	1	
Coal (Mahoning, lower bench)	2	
Shale	15	
Shale, blue, with alternating layers of fine-grained sandstone	20	
Sandstone, massive (Mahoning)	20	
Coal, 1 foot 11½ inches; Bone, 2 inches; Coal, 1 foot 8 inches — Upper Freeport coal	3	9½
Clay, with limestone nodules in lower foot	2	
Limestone, irregularly bedded (Upper Freeport)	1½–3	
Fire clay in places	1±	
Shale	15+	

Extent and development.—The Upper Freeport coal appears above drainage level just east of Ehrenfeld, and has been opened at railroad level by the Pennsylvania, Beech Creek, and Eastern Coal Company at its No. 8 opening. Not far to the west, but higher in the hill owing to the rapid rise of the beds westward, is located mine No. 6 of the same company. This mine was not being worked in the summer of 1906, at the time of visit. West of Mineral Point this coal is present in the hills bordering Conemaugh River, but at varying distances from it. (See Pl. I.) It has been opened in a small way in one or two places, but where seen the openings had fallen in.

South of Conemaugh River it has been worked in and near South Fork by the South Fork Mining Company, and on the west side of South Fork of the Conemaugh by O. M. and H. C. Stineman. It is also present in the hills along the south side of the river, but it has been hardly touched there up to the present time.

Chemical character.—Analysis No. 3, page 40, shows the character of this coal near South Fork. It compares favorably with the other coals in the Johnstown quadrangle, and the analysis shows the normal high carbon content, with low volatile combustible matter. Moisture and ash are also low, but sulphur is high. The product from this coal bed is used chiefly for steaming purposes. It is also coked in beehive ovens at Cresson, Gallitzin, and Bennington with satisfactory results. Its composition along certain parts of the Allegheny Front—at Gallitzin, for instance—is different from that of the coal near South Fork, as the following analyses will show. The percentage of fixed carbon is lower and that of volatile matter higher in the Ebensburg region than on the west side of the basin at South Fork. The coal collected at Sonman, Puritan, and Dunlo, however, is very much the same in composition as that near South Fork and Johnstown.

Analyses of Upper Freeport coal in Ebensburg quadrangle.[a]

	1.	2.	3.	4.	5.	6.	7.
Moisture	0.52	0.63	0.41	1.41	0.43	0.47	0..41
Fixed carbon	66.00	64.43	74.71	71.26	72.89	74.17	73.17
Volatile matter	26.59	27.92	19.41	20.05	17.77	18.44	17.83
Ash	6.89	7.02	5.47	7.28	8.91	6.92	8.59
Sulphur	1.21	.94	1.38	3.34	1.83	1.71	1.53

[a] Ebensburg folio (No. 133), Geol. Atlas U. S., U. S. Geol. Survey, 1905, p. 9. The samples whose analyses are given above were collected by Charles Butts.
1, 2. Pennsylvania, Beech Creek, and Eastern Coal Company, Gallitzin. W. T. Schaller, analyst.
3. Shoemaker Coal Company, Sonman. W. T. Schaller, analyst.
4. G. Pearse & Sons, Puritan. W. T. Schaller, analyst.
5, 6, 7. Mountain Coal Company, Dunlo. Analysis made at Metallurgical Laboratory, Pittsburg, Pa.

Occurrence and physical character.—The Upper Freeport coal about South Fork may occur in either two or three benches, of which only

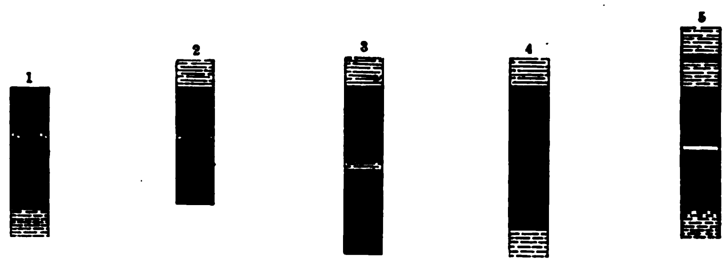

FIGURE 9.—Sections of the Upper Freeport (E or Lemon) coal near South Fork. Scale, 1 inch=5 feet.

1, O. M. Stineman No. 3; 2, H. C. Stineman No. 5; 3, Pennsylvania, Beech Creek and Eastern Coal Company No. 8; 4, natural exposure in railroad cut at Ehrenfeld; 5, South Fork Coal Mining Company No. 2

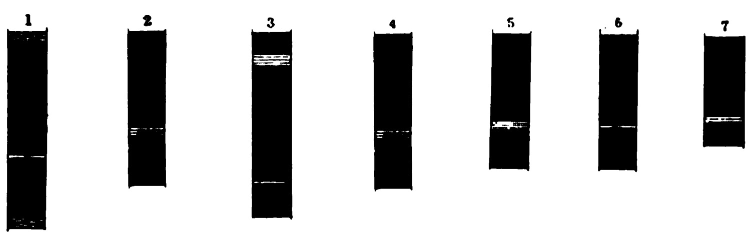

FIGURE 10.—Sections of the Upper Freeport coal along the southeastern margin of the Wilmore Basin (after Butts). Scale, 1 inch=5 feet.

1, Webster No. 11 mine, southeast of Gallitzin, Pa.; 2, Shoemaker mine, Sonman; 3, Hopfer's mine, Trout Run; 4, George Pearse & Sons, Puritan; 5, Beaverdam Run, near Pavia road; 6, Logan Coal Company, Beaverdale; 7, Dunlo.

the two lower are workable, and in this respect it differs essentially from the same coal about Johnstown. At Ehrenfeld and at opening No. 8 of the Pennsylvania, Beech Creek, and Eastern Coal Company, on the opposite side of Conemaugh River, only two benches were observed, and the upper bench is for the most part very much thicker than the corresponding middle bench at places where three are present. The upper of the workable benches ranges in thickness from 1 foot to 2 feet and the lower bench from 1½ to 2 feet. The bone or shale between the two main benches ranges from half an inch to 2 inches. It is very persistent in this district and is usually present also in this bed along the southeast margin of the Wilmore Basin. Figures 9 and 10 show the general similarity of this coal bed on both sides of the Wilmore Basin.

LOWER FREEPORT COAL.

The next lower coal in the South Fork district is the Lower Freeport coal, which lies from 40 to 50 feet below the Upper Freeport coal. It is persistent and is shown in most of the diamond-drill records, but it has not been developed in this district. Locally it is of workable thickness; in some of the well records it measures as much as 2½ feet solid coal with no partings; in others it consists of two benches separated by a thin binder. The two benches taken together would constitute a workable bed. In most of the sections studied it is so badly broken up or so thin as to be of no value; and it therefore can not be classed among the commercial coals in this district at present.

UPPER KITTANNING (CEMENT) COAL.

Name and position.—The next lower coal—the Upper Kittanning (Cement) bed—is an important coal near South Fork. It corresponds to the same bed about Johnstown, though it is not at this time so important as the coal in that district. It occurs nearly midway between the Upper Freeport (Lemon or E) coal and the Lower Kittanning (Miller) bed. North of Conemaugh River, therefore, where the interval between these two coals is only 145 feet (as near New Germany), it occurs about 67 feet below the Upper Freeport coal and about 75 feet above the Lower Kittanning. South of the river, where the interval between the Upper Freeport and Lower Kittanning is approximately 200 feet, it is again about midway between the two, its distance below the former and above the latter ranging from 92 to 105 feet.

Extent and development.—The Upper Kittanning is worked for local supply in the town of South Fork by Robert A. Giles and Charles Hutzel. Other (abandoned) banks in the town were observed. West of the town and on the west side of South Fork it is worked on a considerable scale by H. C. and O. M. Stineman. The coal is present in the hills westward to Mineral Point and beyond. Near Mineral Point two small mines on this coal bed belong to H. W. Gillan. (See Pl. IV, *B*.)

Chemical character.—Analysis No. 5, page 40, indicates the composition of this coal in South Fork. The coal is bright and lustrous and the analysis shows it to be on a par with the corresponding coal in the Johnstown district. Both its ash and sulphur average below those of the coal in that district, but in other respects the analyses are very similar.

To the east, in the Ebensburg quadrangle, this coal is locally workable and has been opened and worked by G. Pearse & Sons at Puritan, on Trout Run. The composition of the coal here, as shown in the table below, is about the same as it is farther west, about South Fork; but analyses of the two samples collected in the same mine show considerable divergence.

Analyses of Upper Kittanning coal at Puritan.

[W. T. Schaller, analyst.]

	1.	2.
Moisture	1.70	0.52
Volatile matter	19.28	22.00
Fixed carbon	71.19	67.49
Ash	7.83	9.99
Sulphur	1.60	3.47

Occurrence and physical character.—In thickness the coal ranges from 3 to 3½ feet, usually without any partings, and has a hard shale roof which gives no trouble. There is in places a few inches of bone

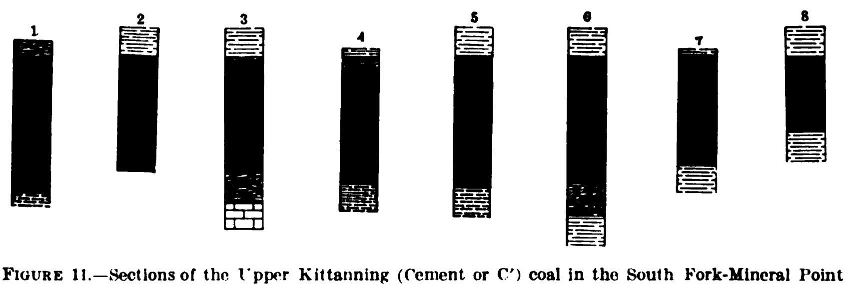

FIGURE 11.—Sections of the Upper Kittanning (Cement or C') coal in the South Fork-Mineral Point district. Scale, 1 inch=5 feet.

1, H. C. Stineman No. 6, South Fork; 2, O. M. Stineman, No. 3½, South Fork; 3, Robert A. Giles, South Fork; 4, Charles Hutzel, South Fork; 5, Old opening, southern part of South Fork; 6, 7, H. W. Gillan, near Mineral Point; 8, Salt Lick Run.

at the top, which is discarded in mining. The lower part of the coal is locally bony. Below this, and in its absence directly below the coal, there is a band of clay, ranging from a few inches to more than 2 feet. Below the clay, or just below the coal itself, is found a bed of limestone or cement rock—the Johnstown limestone member—measuring in places as much as 4 feet.

Figure 11 indicates graphically what has been outlined above. In the area to the east the coal is locally workable, and where exploited by G. Pearse & Sons, on Trout Run, on the east side of the basin, in the Ebensburg quadrangle, its thickness is very much the same as near South Fork. At Bennington it is 2 feet 10 inches thick; in the Sonman shaft it is 2 feet; in the Yellow Run shaft 2 feet 6 inches; and in a diamond-drill hole of the Henriette Mining Company, south of Llanfair, it is 1 foot thick. On the east side of the basin, therefore, it can not be considered more than locally workable. On the west side of the basin it may be regarded as among the future important coals, both near South Fork and in the region to the south, where considerable exploratory work with the diamond drill has showed this coal to be 3 feet or more in thickness.

LOWER KITTANNING (MILLER) COAL.

Name and position.—The Lower Kittanning, Miller, B, or White Ash bed is the most important coal in the South Fork-Mineral Point district. Immediately about South Fork it lies 160 feet below the Upper Freeport bed; elsewhere it ranges from 145 to 200 feet below the Upper Freeport coal (see p. 24) and about half as much below the Upper Kittanning (Cement) bed. Its position, approximately 55 to 65 feet above the top of the Pottsville (or "conglomerate rock," as the Pottsville is popularly called), should serve to locate and identify it with little trouble in the South Fork-Mineral Point district.

Extent and development.—North of Conemaugh River the coal has been opened by the Pennsylvania, Beech Creek, and Eastern Coal Company and worked at its No. 3 and No. 5 mines, the workings in the latter being on the dip of the bed. Farther west the Priscilla Coal Company is working the same bed, and still beyond, near the Ebensburg (Viaduct) anticlinal axis, are the openings of the Keystone Coal and Coke Company, called Argyle Nos. 1 and 2 mines. There are also a few abandoned mines on the Lower Kittanning bed north of Conemaugh River, and to judge from the culm heaps at their tipples large bodies of coal have been removed from them.

South of the river and west of South Fork the workings on the Lower Kittanning coal are extensive. The mines here include collieries Nos. 2 and 4 of the Stineman Coal and Coke Company and colliery No. 1 of the Stineman Coal Mining Company. To the east and in the town itself are the workings of the South Fork Coal Mining Company. The magnitude of the coal industry at South Fork may be judged from the fact that in 1905 there were produced in these mines 1,400,000 tons of coal, valued at $1,500,000.

Chemical character.—Analyses Nos. 15, 16, 28, and 29 (pp. 40–42) give an excellent idea of the high grade of this coal as mined near South Fork. The analyses below give an idea of its composition in the Ebensburg quadrangle, on the southeast flank of the Wilmore Basin.

Analyses of Lower Kittanning (Miller) coal in the Ebensburg quadrangle.[a]

[Air-dried samples; W. T. Schaller, analyst.]

	1.	2.	3.	4.	5.	6.	7.
Moisture	0.53	0.32	0.57	0.38	0.36	0.35	0.43
Volatile matter	26.90	21.97	23.52	19.44	20.46	17.81	19.41
Fixed carbon	63.52	71.38	69.64	74.28	72.76	74.28	75.78
Ash	9.05	6.33	6.27	5.90	6.42	7.56	4.38
Sulphur	1.21	.68	.99	.72	1.74	3.14	.76

[a] Ebensburg folio (No. 133), Geol. Atlas U. S., U. S. Geol. Survey, 1905, p. 9.

1. Reed & Bradley mine, Bennington.
2, 3. Lilly Mining Company, Bear Rock Run.
4. A. C. Blowers, Bens Creek.
5, 6. Alton Coal Company, Lloydell.
7. Henriette Coal Company, near Llanfair.
1 to 6 collected by Charles Butts; 7 by W. C. Phalen.

From the analyses (pp. 40–42) it appears that the fixed carbon in the samples collected in the Johnstown quadrangle, near South Fork, ranges from 74 to more than 78 per cent, with volatile matter ranging from 14 to more than 16 per cent. The moisture of the samples as received at the laboratory is low, not exceeding 3.5 per cent. The samples from South Fork are notably low in sulphur and ash and show the excellent character of the Lower Kittanning (Miller) coal in this part of the Wilmore Basin. The samples collected from the Ebensburg quadrangle by Charles Butts and W. C. Phalen during the summer of 1903 were analyzed in the chemical laboratory of the Survey at Washington and not in the laboratory of the technologic branch of the Survey at St. Louis. The results of analyses are therefore not strictly comparable with the results of analyses from South Fork (pp. 40–42). The former show more diversity in composition, as would naturally be expected when the scattered places from which the samples were collected are considered. The general similarity of the results, however, is noteworthy, as is also the low content in sulphur and ash. The second sample collected from the Alton Coal Company's mine at Lloydell (No. 6, above) seems to be entirely exceptional regarding its sulphur content, and it is probable that a "sulphur ball" found its way into the sample without being suspected.

Steaming tests.—As a steam coal the Lower Kittanning (Miller) coal from the South Fork district ranks among the very best of western Pennsylvania and probably equals in steaming value any other steam coal in this part of the State. (See comparative tables, p. 37.)

In the following tables are given the results of tests on run-of-mine coal loaded under the supervision of J. S. Burrows, formerly of the Survey, collected from No. 3 mine of the Pennsylvania, Beech Creek, and Eastern Coal Company, at Ehrenfeld. One coking test, five steaming tests, and one producer-gas test were made on the carload sample collected.[a] A steaming test was also made on this sample mixed with coal from the Darby mine of the Darby Coal and Coke Company, at Darby, Lee County, Va., but the results of this test are not given in the bulletin cited.

The analysis of the carload sample tested is as follows (for mine samples see analyses 28 and 29, pp. 41–42):

Analysis of carload sample of Lower Kittanning coal from South Fork-Mineral Point district.

Laboratory No.		2152
Air-drying loss		2.90
Proximate.	Moisture	3.51
	Volatile matter	16.82
	Fixed carbon	73.04
	Ash	6.63
Ultimate.	Sulphur	.94
	Hydrogen	4.56
	Carbon	80.70
	Nitrogen	1.26
	Oxygen	5.91
Calorific value determined:		
	Calories	7,933
	British thermal units	14,279

The results of the steaming tests on this coal are as follows:

Steaming tests on Lower Kittanning coal from South Fork-Mineral Point district.

	Test 236.	Test 237.	Test 238.	Test 239.	Test 242.
Heating value of coal..B. t. u. per pound of dry coal..	14,886	14,868	14,828	14,690	14,659
Force of draft:					
Under stack damper.........inch water..	0.43	0.45	0.50	0.63	0.47
Above fire.........do....	.15	.16	.17	.19	.16
Furnace temperature.........°F..	2,317	2,266	2,212	....	2,059
Dry coal used per square foot of grate surface per hour.........pounds..	15.74	16.23	15.69	17.64	14.33
Equivalent water evaporated per square foot of water-heating surface per hour.........pounds..	2.93	2.96	2.93	3.08	2.92
Percentage of rated horsepower of boiler developed...	82.0	83.0	82.1	86.5	81.9
Water apparently evaporated per pound of coal as fired.........pounds..	8.51	8.27	8.44	7.98	8.52
Water evaporated from and at 212° F.:					
Per pound of coal as fired.........do....	10.12	9.85	10.05	9.52	10.17
Per pound of dry coal.........do....	10.37	10.17	10.42	9.75	10.22
Per pound of combustible.........do....	11.20	11.02	11.29	10.71	11.15
Efficiency of boiler, including grate.........per cent..	67.27	66.06	67.86	64.10	67.19
Coal as fired:					
Per indicated horsepower hour.........pounds..	2.79	2.87	2.81	2.97	2.78
Per electrical horsepower hour.........do....	3.45	3.54	3.47	3.67	3.43
Dry coal:					
Per indicated horsepower hour.........do....	2.73	2.78	2.71	2.90	2.77
Per electrical horsepower hour.........do....	3.37	3.43	3.35	3.58	3.41
Proximate analysis:					
Moisture	2.37	3.11	3.56	2.44	0.42
Volatile matter	16.74	15.68	16.09	16.64	17.51
Fixed carbon	74.66	74.93	73.85	73.69	75.20
Ash	6.23	6.28	6.50	7.23	6.87
	100.00	100.00	100.00	100.00	100.00
Sulphur	.88	.89	.87	1.12	1.01

[a] Bull. U. S. Geol. Survey No. 290, 1906, pp. 178–181.

Steaming tests on Lower Kittanning coal from South Fork-Mineral Point district—Continued.

	Test 236.	Test 237.	Test 238.	Test 239.	Test 242.
Ultimate analysis:					
Carbon[a]	84.14	84.03	83.81	82.98	83.35
Hydrogen[a]	4.34	4.35	4.33	4.28	4.15
Oxygen[a]	2.93	2.91	2.91	2.89	3.27
Nitrogen[a]	1.31	1.31	1.31	1.29	1.32
Sulphur	.90	.92	.90	1.15	1.01
Ash	6.38	6.48	6.74	7.41	6.90
	100.00	100.00	100.00	100.00	100.00

[a] Figured from car sample.

Test 236: Size as shipped, run of mine. Size as used, over 1 inch, 6.5 per cent; ½ inch to 1 inch, 13.6 per cent; ¼ inch to ½ inch, 22.4 per cent; under ¼ inch, 57.5 per cent. Duration of test, 9.88 hours. Kind of grate, rocking.

Test 237: Size as shipped, run of mine. Size as used, over 1 inch, 5.8 per cent; ½ inch to 1 inch, 12.3 per cent; ¼ inch to ½ inch, 19.5 per cent; under ¼ inch, 62.4 per cent. Duration of test, 10 hours. Kind of grate, rocking.

Test 238: Size as shipped, run of mine. Size as used, over 1 inch, 5.4 per cent; ½ inch to 1 inch, 9.1 per cent; ¼ inch to ½ inch, 14.9 per cent; under ¼ inch, 70.6 per cent. Duration of test, 10.02 hours. Kind of grate, rocking.,

Test 239: Size as shipped, run of mine. Size as used, over 1 inch, 4.4 per cent; ½ inch to 1 inch, 8.8 per cent; ¼ inch to ½ inch, 16.2 per cent; under ¼ inch, 70.6 per cent. Duration of test, 9.92 hours. Kind of grate, rocking.

Test 242: Size as shipped, run of mine. Size as used, over 1 inch, 2.0 per cent; ½ inch to 1 inch, 7.0 per cent; ¼ inch to ½ inch, 14.5 per cent; under ¼ inch, 76.5 per cent. Dried coal. Duration of test, 7.88 hours. Kind of grate, plain.

The figure giving the number of pounds of water evaporated by 1 pound of dry coal from and at a temperature of 212° F. gives the results of the coal tested so far as these relate to its commercial value, and the reader is referred to the table on page 37 for the standing of the Ehrenfeld coal among other standard steaming coals. The results of the tests, on the Ehrenfeld samples though showing a range of 9.75 to 10.42 pounds of water evaporated per pound of dry coal used, are yet, when averaged, among the very best made at the testing plant.

Coking tests.—The coal from the lower Kittanning bed near South Fork has been coked, and the results of the test on the sample from Ehrenfeld are given below:

Coking test on Lower Kittanning coal from Ehrenfeld.

[Run of mine; finely crushed; raw; duration of test, 51 hours.]

Coal charged	pounds..	10,000
Coke produced	do....	5,223
Breeze produced	do....	1,600
Coke produced	per cent..	52.23
Breeze produced	do....	16.00
Total percentage yield		68.23

The product was a soft, dense coke of a dull-gray color, in large and small chunks. There was a heavy black butt on the coke, and it was hard to burn. The cell structure was small.

Analyses of coal and coke.

	Coal.	Coke.
Moisture	3.32	0.91
Volatile matter	15.56	2.16
Fixed carbon	74.29	88.99
Ash	6.83	7.94
Sulphur	1.12	.91

The yield of coke from this test is comparatively high, but the poor quality of the coke shows that the coal does not belong among the best coking coals of western Pennsylvania and West Virginia. Coke made by the Cambria Steel Company with coal mined from this bed about Ehrenfeld proved well adapted to metallurgical purposes. The yield also was satisfactory.

Cupola tests.[a]—In connection with the tests of coals made at the plant of the United States Geological Survey at St. Louis in 1904 practical melting tests were made of coke that showed any likelihood to be of value to the foundry industry. Among those tested was one made from coal collected at colliery No. 3 of the Pennsylvania, Beech Creek, and Eastern Coal Company at Ehrenfeld. The test was conducted in a 36-inch foundry cupola lent by the Whiting Foundry Equipment Company, of Chicago. The 36-inch shell of the cupola was relined to 26 inches internal diameter. There were four horizontal tuyeres measuring 4 by 6 inches on the outside and 3 by 13 inches on the inside of the cupola, which were situated 11 inches above the sand bottom. The total tuyere area was 96 square inches, giving a ratio of 1 to 5.96 with the cupola area. A No. 6 Sturtevant fan run at 2,514 revolutions a minute furnished the blast, which was kept at about 7 ounces.

The cupola test was conducted by W. G. Ireland, and the details of the method employed are outlined in the references cited above and will not be given here. The results of the test are shown in the following table:

[a] Prof. Paper U. S. Geol. Survey No. 48, pt. 3, 1906, pp. 1367-1370; Bull. U. S. Geol. Survey No. 336, 1908, pp. 48, 49, 50, 54, 57, 60, 63.

Cupola tests on Lower Kittanning (Miller) coal from Ehrenfeld.

Cupola test No.	Date.	Charges (pounds).																		Ratio iron to coke.
		Coke bed.	Pig iron.	Scrap.	Coke.	Pig iron.	Scrap.	Coke.	Pig iron.	Scrap.	Coke.	Pig iron.	Scrap.	Coke.	Pig iron.	Scrap.	Total.			
																	Coke.	Pig iron.	Scrap.	
	1906.																			
65	September 19	180	540	180	63	428	143	63	428	143	62	427	142	62	427	142	430	2.250	750	7
188	December 7	195	585	195	59	417	139	59	416	139	59	416	139	58	416	138	430	2,250	750	7

Cupola test No.	Analysis of coke (per cent).									Record of melt.											
	Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.		Phosphorus.	Specific gravity.	Fluidity strip (per cent), full.	Maximum blast pressure (ounces).	Pounds of iron.			Melting rate.		Recovered (pounds).		Melting loss (per cent).	Melting ratio.		Coke bed.	
					In coke.	In ash.					Poured.	Additional melted.	Total.	Per hour (pounds).	Increase or decrease.	Iron.	Coke.		Iron to coke.	Increase or decrease.	Increase (+) or decrease (−) (pounds).	Height above top of tuyeres (inches).
65	0.91	2.16	88.99	7.94	0.91	0.10	0.0049	1.76	98.61	7	1,939	565	2.504	5,181	....	228	81	9.07	7.20	....	....	....
188	.91	2.16	88.99	7.94	.91	.10	.0049	1.76	93.05	7	2,256	257	2,513	5,799	Increase.	199	49	9.60	6.50	Decrease.	+15	16.33

Cupola tests on Lower Kittanning (Miller) coal from Ehrenfeld—Continued.

Cupola test No.	Record of melt—Continued.																			
	Blast on at—	Iron running.	Weight and time of each ladle of melted iron.																	
			Lbs.	At—	Lbs.	At—	Lbs.	At—	Lbs.	At—	Lbs.	At—	Lbs.	At—	Lbs.	At—	Lbs.	At—	Lbs.	At—
65	11.35 a. m.	11.42	22	11.47	89	11.50	74	11.50½	79	11.52	96	11.52½	91	11.53	66	11.55	82	11.55½	80	11.56
188	3.34 p. m.	3.42	88	3.47	94	3.47½	30	3.48	78	3.50	80	3.50½	58	3.51	86	3.52	88	3.52½	71	3.53

Cupola test No.	Record of melt—Continued.																			
	Weight and time of each ladle of melted iron—Continued.																			
	Lbs.	At—	Lbs.	At—	Lbs.	At—	Lbs.	At—	Lbs.	At—	Lbs.	At—	Lbs.	At—	Lbs.	At—	Lbs.	At—	Lbs.	At—
65	62	11.57	95	11.57½	68	11.58	81	11.59	75	11.59½	68	12.00	74	12.01	146	12.01½	72	12.02	85	12.04	136	12.04½
188	84	3.54	86	3.54½	79	3.55	86	3.56	89	3.56½	80	3.57	87	3.58	90	3.58½	78	3.59	89	4.00	83	4.00½

Cupola test No.	Record of melt—Continued.												Melting time (minutes).	Remarks.
	Weight and time of each ladle of melted iron—Continued.													
	Lbs.	At—	Lbs.	At—	Lbs.	At—	Lbs.	At—	Lbs.	At—	Lbs.	At—		
65	50	12.05	79	12.08	95	12.08½	48	12.10½	26	12.11	.....	....	29	Iron hot.
188	66	4.01	87	4.02	87	4.02½	88	4.04	92	4.04½	89	4.06	26	Iron hot; 27th ladle—79 pounds at 4.07; 28th ladle—58 pounds at 4.08.

Producer-gas test.—The following results were obtained from the producer-gas test made on the Ehrenfeld sample:

Producer-gas test on Lower Kittanning coal from Ehrenfeld.[a]

	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower per hour.			
Per electrical horsepower:	*Pounds.*	*Pounds.*	*Pounds.*
Available for outside purposes	1.25	1.22	1.13
Developed at switchboard	1.18	1.15	1.07
Per brake horsepower:			
Available for outside purposes	1.06	1.04	.96
Developed at engine	1.00	.98	.91
Equivalent used by producer plant.			
Per electrical horsepower:			
Available for outside purposes	1.35	1.32	1.22
Developed at switchboard	1.28	1.25	1.15
Per brake horsepower:			
Available for outside purposes	1.15	1.12	1.04
Developed at engine	1.09	1.06	.98

[a] Bull. U. S. Geol. Survey No. 290, 1906, pp. 180-181.

Size as shipped, run of mine; size as used, not determined. Duration, 50 hours. Average electrical horsepower, 187.9; average British thermal units gas per cubic foot, 133; total coal fired, 11,100 pounds.

Analyses.

Coal.		Gas by volume.	
Moisture	2.49	Carbon dioxide (CO_2)	9.9
Volatile matter	16.61	Carbon monoxide (CO)	18.7
Fixed carbon	73.70	Hydrogen (H_2)	14.1
Ash	7.20	Methane (CH_4)	2.2
		Nitrogen (N_2)	55.1
	100.00		
Sulphur	.91		100.0

Occurrence and physical character.—The Lower Kittanning coal near South Fork (see fig. 12) has a section similar to that of the bed near Johnstown, already described. Its main bench, however, is thicker, averaging nearly 4 feet and in some places reaching 5 feet, with no partings. The double structure—that is, the occurrence of a main bench with the under coal—which is fairly persistent in the Johnstown district, is even more apparent about South Fork. Some of the mines, however, show it only here and there. In other physical aspects this coal resembles the Lower Kittanning bed about Johnstown. Its roof of dense shale or sandstone, the general absence of "draw slate" or of clay veins, and the irregular floor are all common to the bed in both districts. The top few inches of the coal is usually bony and has to be discarded. In appearance the coal is lustrous and much of it is iridescent, and its columnar cleavage is one of its more characteristic features.

The lower bench varies in thickness, but is in places as much as 2 feet thick; this thickness is reached near both South Fork and Mineral Point. The lower coal is underlain by valuable plastic clay and is separated from the main bench by a few inches to a foot of clay or shale. So far as known, the under coal is not utilized. As a rule it is not so persistent along the southeastern margin of the Wilmore Basin if the sections obtained by Mr. Butts and Mr. Phalen

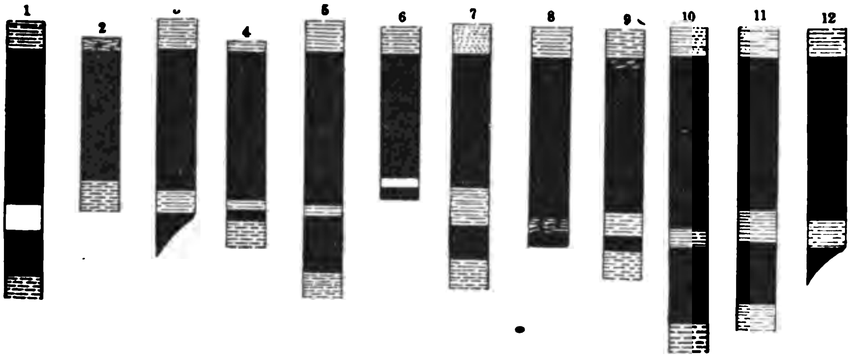

FIGURE 12.—Sections of Lower Kittanning (Miller or B) coal in the South Fork-Mineral Point district. Scale, 1 inch=5 feet.

1. Keystone Coal and Coke Company, Argyle No. 2, South Fork.
2. Keystone Coal and Coke Company, Argyle No. 1, South Fork.
3. Priscilla Coal Company, South Fork.
4. Pennsylvania, Beech Creek and Eastern Coal Company, Ehrenfeld.
5. Stineman Coal and Coke Company, No. 2, South Fork.
6. Stineman Coal and Coke Company, No. 4, South Fork.
7. Stineman Coal Mining Company, No. 1, South Fork.
8. Stineman Coal and Coke Company, No. 2, Timber opening, South Fork.
9. South Fork Coal Mining Company, No. 1, South Fork.
10. Valley Smokeless, No. 3, Mineral Point.
11. Page & Reighard, Juniper mine, Mineral Point.
12. George Schafer, Mineral Point.

in 1903 are representative. It here appears locally, as the following section shows:

Section of Lower Kittanning (Miller) coal at Henriette shaft No. 1, Llanfair, Pa.

	Ft.	In.
Coal	3	9
Slate		3
Coal		11
Clay.		

LOWER ALLEGHENY COALS.

A coal 65 feet below the Lower Kittanning (Miller) bed has been opened at a few points about South Fork and Mineral Point. This coal probably corresponds to the Brookville or A coal. Most of the openings have fallen shut, but one bank is mined at South Fork to supply the local brick company. The coal is better known locally as the Dirty A or Six-foot coal, but where measured (see fig. 13) only 3½ feet of coal was observed. The bone parting observed a foot from the base is only an inch thick. The roof is shale or sandstone and so far as known gives no trouble. The coal runs as thick as 5 feet and as thin as 3 feet. According to reports, 4 feet may be considered an average. The coal is reported not to be rolly and no clay veins of importance have been encountered.

FIGURE 13.—Section of the Brookville (A) coal at the mine of J. H. Wickes, South Fork. Scale, 1 inch=5 feet.

It has a composition indicated by analysis 36, page 41. From the high ash and sulphur content, aggregating more than 15 per cent, the coal deserves the name Dirty A, which is often applied to it. In other respects the analysis corresponds with those of other coals of the area, being relatively high in fixed carbon and low in volatile matter. It is possible that the coal may be valuable in this district, but the fact that it has not been developed on an extensive scale and apparently has not come into competition with the other coals of the district is strong presumptive evidence that in quality it is not up to the standard of the other coals mined about South Fork.

POTTSVILLE COALS.

But one other coal in the South Fork-Mineral Point district deserves brief attention. This is the coal associated with the flint clay (see pp. 121–123) at the Mercer horizon. The coal is not worked and where observed was merely a thin streak in the middle of the clay. The following section was seen and measured at the clay mine of J. H. Wickes:

Section of clay and coal at Mercer horizon, South Fork.

	Ft.	In.
Roof, heavy sandstone.		
Plastic clay	3½	
Coal		⅛–2
Flint clay	4½	
Sandstone.		

Though the coal is not workable here, it is quite possible that it may be of workable thickness locally. In this district, however, it can not be regarded as among the commercial beds of the future.

BLACKLICK CREEK DISTRICT.

EXTENT.

In the Blacklick Creek district will be included the coal occurrences along Blacklick Creek and its South Branch. Operations on these coals are confined almost exclusively to the creek valley, the principal mining towns being Nanty Glo, Cardiff, Twin Rocks, Weber, Vintondale, and Wehrum. The coals outcrop from Nanty Glo, where they are brought above drainage level on the east margin of the Laurel

Ridge anticline, westward to Vintondale, on the west flank of the same anticline. Just west of Vintondale the highest workable coal disappears below drainage level, and still farther west, at Wehrum, mining operations are conducted by means of a shaft. West of Wehrum the coal-bearing beds are brought above drainage level just at the western edge of the quadrangle, near Dilltown. A few country banks have also been opened on Mardis Run.

GEOLOGIC POSITION OF COALS.

Figure 2 shows the relations between the principal coals in the Blacklick Creek district, and the following section, measured along the railroad and in the hills north of Vintondale, shows the character of the beds which make up the intervals:

Section north of Vintondale.

		Ft.	in.
Sand and shale		9	
Coal, reported 42 inches, thinning to 18 inches when run in from the outcrop (D coal).			
Concealed		57	
Sandstone		15	
Concealed		10½	
Shale, sandy		5	
Concealed		10½	
Shales, brown-drab		10	
Coal, 2 feet 3 inches Clay, 1 inch Coal, 6½ inches	Middle Kittanning (C) coal	2	10½
Shales		7	8
Chiefly clay		5	2
Sandstone		3	1
Shale, black		2	4
Sandstone with black shale partings		5	2
Shale, sandy, becoming concretionary and ferruginous at base.		20	8
Interval		4	
Shale, variegated black and drab		6	
Coal, 3 feet 8 inches Shale, 2 inches Coal, 4 inches Clay, 2 inches Coal, 9 inches	Lower Kittanning (B or Miller) coal	5	1
Shales, sandy			6
Fire clay, dark gray		3	5
Sandstone, drab, resembling ganister			2–3
Clay, light drab		3	

The Middle Kittanning (C) coal, the first above the Lower Kittanning (Miller or B) bed, which is the coal worked along Blacklick Creek, occurs at an interval above it of about 50 feet. This coal is nearer the Lower Kittanning at Nanty Glo, having been reported only 34 feet above it near the opening of the Ivory Hill Mining Company at that place. At Big Bend its interval above the Lower Kittanning is about 45 feet.

There is still another coal at the top of the section deserving attention. At Vintondale a gully was dug up the hill from railroad level where the Lower Kittanning coal outcrops. The section given above, except the part between the Lower and Middle Kittanning coals, was measured in this gully. The top coal was observed by hand level to be 108 feet above the intermediate (Middle Kittanning or C) coal, and the interval between the Lower and Middle Kittanning beds was found to be 46½ feet. Thus from the top coal to the Lower Kittanning (B) bed the distance is about 164 feet. At Nanty Glo a workable coal (probably the Lower Freeport or D coal) was observed by hand-level measurement to occur 150 feet above the Lower Kittanning coal, and at Twin Rocks a coal was reported at almost exactly the same interval by the engineer of the Big Bend collieries. At Wehrum certain of the diamond-drill records show a coal about the same interval above the Lower Kittanning coal. So far as the writers are aware, this is the highest coal of any importance in the Blacklick Creek district. About 50 feet above it occurs an unworkable small coal, which is regarded as the equivalent of the Upper Freeport or E bed. The highest workable coal along Blacklick Creek will therefore be regarded tentatively as the Lower Freeport (D) coal.

The nomenclature of the coals discovered in the Blacklick Creek district and the intervals between them have been graphically given by D'Invilliers.[a] He places the first coal above the Lower Kittanning (B) at 60 feet above it, but the hand-leveled sections at Vintondale, as well as measurements made at Twin Rocks and reports from authorities at Nanty Glo, make this coal at least 15 feet lower, and instead of lettering it C′, as D'Invilliers has done, the writers prefer to regard it as the C coal and the representative of the Middle and not the Upper Kittanning bed. Further, D'Invilliers places the next higher coal at 120 feet above the Lower Kittanning (B) and the next at approximately 60 feet higher. This bed, which he denotes as the E with a question, he describes as a "good bed, thinning westward to about 3 feet." It is believed that this is the coal measured at Nanty Glo, at Twin Rocks, near Rexis, and on Mardis Run, though the interval obtained (150 to 160 feet above the Lower Kittanning bed) falls short by at least 20 feet of the interval platted by D'Invilliers.

ALLEGHENY COALS.

LOWER FREEPORT (D) COAL.

Name and position.—Some question arises as to whether the highest workable coal in the Allegheny formation is the Upper or Lower Freeport. It is quite certain that the full complement of coals in the formation is not developed along Blacklick Creek, at

[a] Summary Final Rept. Geol. Survey Pennsylvania, 1895, pl. 415, p. 2222.

least not as clearly as in the Johnstown Basin. Only three workable coals in the Allegheny (above and including the B bed) were determined with any certainty, and, though more may be present, they must be small and hence of no value except for stratigraphic purposes.

The position of the highest workable coal is very definitely fixed. At Nanty Glo it is just 150 feet by hand level above the Lower Kittanning (B) bed. On the Selderville road, between Nanty Glo and Twin Rocks, the interval, measured by barometer, is 158 feet; at Vintondale, by hand level, it was made 164 feet; and, as stated by the engineer of the Big Bend collieries, the interval at Big Bend is about 150 feet. There is a question as to whether this coal is the Upper Freeport or the Lower Freeport, and this question the writers are unable to settle definitely. Objection should not be made to its being considered as the Upper Freeport on the basis of its small interval above the Lower Kittanning coal, as this interval is even less than 150 feet at New Germany. In this report, however, it will be regarded as the Lower Freeport coal.

Extent and development.—The Lower Freeport (D) coal has been opened by the Ivory Hill Coal Mining Company east of Nanty Glo and on the side of the hill just west of the No. 14 colliery of the Pennsylvania, Beech Creek, and Eastern Coal Company. It has been prospected and its position and character are well known at Twin Rocks and to the northeast, opposite No. 2 colliery of the Big Bend Coal Mining Company. About Vintondale it has been prospected and its character is known, as a section of the coal near Rexis was measured by Mr. Martin. On Mardis Run, just off the northwest corner of the Johnstown quadrangle, the coal is opened and a section was measured. At present it is not a commercial factor in the Blacklick Creek district, but it can be classed among the future commercial coals of this district.

Occurrence and physical character.—Figure 14 shows the mode of occurrence of the Lower Freeport coal. It generally consists of two

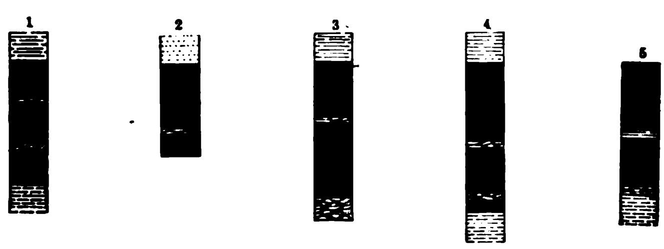

FIGURE 14.—Sections of the Lower Freeport (D) coal along Blacklick Creek. Scale, 1 inch = 5 feet.
1, Mardis Run near northwest edge of Johnstown quadrangle; 2, Blacklick Creek near Rexis; 3, road south of Twin Rocks; 4, Twin Rocks; 5, Ivory Hill Coal Mining Company, Nanty Glo.

or three benches separated by thin bone partings, the coal aggregating from 3 to 3½ feet in thickness. At Vintondale, Twin Rocks, and Nanty Glo the upper bench varies from 1½ to nearly 2 feet in thickness, and the lower bench averages about 15 inches, with some few inches of bone beneath. At Twin Rocks this is underlain by a few inches of coal. On Mardis Run the coal is more broken, consisting of three benches, each about a foot thick. The roof is usually shale and the coal is underlain by clay. The presence of the parting in this coal has been a drawback to operations on it, but it is quite probable that it will yet be worked; in fact, it was worked during the hard-coal famine of 1902–3 and gave satisfaction. If proper care is exercised in separating the bony parting, it should be readily marketed. The resemblance of the sections to those of the Upper Freeport coal near South Fork is marked.

MIDDLE KITTANNING COAL.

A little more than 100 feet below the Upper Freeport coal and from 35 to 45 feet above the main coal of the Blacklick district (Lower Kittanning or Miller bed) occurs a coal which is persistent along South Branch of Blacklick Creek. It has been observed at Twin Rocks, Nanty Glo, and Vintondale, and its interval with respect to the main Blacklick coal has been measured at the two last-named places. It has been called the Middle Kittanning coal because it is the first coal above the Lower Kittanning bed. At Vintondale the following section was measured:

Section of Middle Kittanning coal at Vintondale.

	Ft.	in.
Shale roof.		
Coal	2	3
Clay		1
Coal		6½
Clay.		

The coal here has a thickness of 33½ inches and is therefore workable. Owing to its persistence, it may be regarded as among the coals that will in the future be worked in this region, though it may be some time before it will be necessary to draw on this coal as a source of supply.

LOWER KITTANNING (B) COAL.

Name and position.—The main coal of the Blacklick district is considered the Lower Kittanning (Miller or B) coal and corresponds to this coal about South Fork. Some question has been raised as to this correlation and the coal has been regarded as the equivalent of the Upper Kittanning or C′ coal. The objections to the latter view have been summed up by D'Invilliers[a] in the following words, with which the writers are in full agreement.

The whole character of the "Blacklick seam" is totally unlike the appearance of the Kittanning upper bed (C′) as exposed anywhere in Clearfield, Cambria, or Somerset counties. On the other hand, its double structure, columnar cleavage, partings, roof

[a] Summary Final Rept. Geol. Survey Pennsylvania, 1895, p. 2222.

and floor, and excellent chemical character most strongly resemble the features of the Kittanning lower bed (B or Miller seam), all through southern Cambria and especially in the Paint and Shade Creek valleys of Somerset County. * * * At no place in the Blacklick region has the cement bed been noticed beneath this coal, which would identify it as bed C′.

Extent and development.—This coal is often referred to as the Blacklick Creek seam. It appears above drainage level just east of Nanty Glo, on South Branch of Blacklick Creek, where it has been opened by the Ivory Hill Coal Mining Company. In the southern part of Nanty Glo are two important mines on this coal—the Pennsylvania, Beech Creek, and Eastern Coal Company's colliery No. 14 and that of the Nanty Glo Coal Mining Company. Some distance north of the town is the mine of the Lincoln Coal Company, and still farther north, near the edge of the quadrangle, is the opening of the Cardiff Coal Company. The next mining center to the west is Twin Rocks or Expedit post-office, near which are located collieries Nos. 1 and 2 of the Big Bend Coal Mining Company and colliery No. 3 of the Commercial Coal Mining Company. Colliery No. 4 of the latter company is located about 4 miles farther west, at a little settlement called Weber. The Vinton Colliery Company controls the workings on this bed about Vintondale. Four out of its five collieries were active in the summer of 1906 and colliery No. 6 was just being opened. The coal goes below drainage level in the town and the operations to the west at Wehrum are conducted by shafting for the coal to a depth of 187 feet. On the west side of the Barnesboro or Westover Basin the bed appears above drainage level just at the edge of the quadrangle and has been worked in a small way by H. R. Dill about a mile northwest of Dilltown. The development of this coal along Blacklick Creek is of recent date, and the production of this district, which was only 5,000 tons in 1894, had increased in 1905 to 1,045,802 tons, valued at $1,019,617.

Chemical character.—The composition of this coal is indicated by analyses 17 to 27 (pp. 40–41). This exceptionally complete series of analyses shows that the Lower Kittanning (Miller) coal has much the same character along Blacklick Creek as at Johnstown and South Fork. The moisture in the coal is low, in no sample exceeding 4 per cent. The volatile matter is likewise low and remarkably uniform, ranging from more than 17 per cent to less than 19 per cent. Fixed carbon ranges from 67 to 73 per cent—a slight range considering that the samples were obtained by three individuals from scattered mines. Ash is on the whole low, but sulphur is rather high, in one sample exceeding 4½ per cent. As a whole, however, the figures all point to a high-grade coal.

Steaming tests.—Steaming tests have been made on Lower Kittanning coal collected at Wehrum by the United States Geological Survey.[a] The analyses on the samples used are as follows:

[a] Bull. U. S. Geol. Survey No. 332, 1908, pp. 201-202.

Chemical analyses of Lower Kittanning coals from Wehrum.[a]

		Test 472.	Test 473.	Test 467.
Prox.	Moisture	1.88	2.45	3.90
	Volatile matter	17.60	17.55	23.35
	Fixed carbon	69.06	70.56	64.65
	Ash	11.46	9.44	8.10
	Sulphur	5.37	3.87	3.11
Ult.	Hydrogen	4.13	4.31	4.35
	Carbon	75.63	78.83	78.71
	Nitrogen	1.15	1.21	1.09
	Oxygen	1.94	2.00	4.18
	Ash	11.68	9.68	8.43
	Sulphur	5.47	3.97	3.24

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample. (See analyses 10 and 11, pp. 40-41.)

The results of the steaming tests are as follows:

Steaming tests on Lower Kittanning coal from Wehrum.

	Test 472.[a]	Test 473.[a]	Test 467.
Size as used:			
Over 1 inch ... per cent	8.2	4.6	....
½ inch to 1 inch ... do	11.1	6.9	....
¼ inch to ½ inch ... do	19.2	13.9	....
Under ¼ inch ... do	61.5	74.6	....
Average diameter ... inch	0.41	0.31	....
Duration of test ... hours	8.75	9.77	8.87
Heating value of fuel ... B. t. u. per pound of dry fuel	13,729	14,240	14,258
Force of draft:			
Under stack damper ... inch of water	0.81	0.82	0.76
Above fire ... do	.27	.23	.17
Furnace temperature ... °F	2,512	2,615	2,753
Dry fuel used per square foot of grate surface per hour ... pounds	16.87	17.24	17.63
Equivalent water evaporated per square foot of water-heating surface per hour ... pounds	3.00	3.25	3.53
Percentage of rated horsepower of boiler developed	84.2	91.2	99.00
Water apparently evaporated per pound of fuel as fired ... pounds	7.27	7.65	7.98
Water evaporated from and at 212° F.:			
Per pound of fuel as fired ... do	8.76	9.22	9.65
Per pound of dry fuel ... do	8.93	9.45	10.04
Per pound of combustible ... do	10.57	10.85	11.30
Efficiency of boiler, including grate ... per cent	62.81	64.09	68.00
Fuel as fired:			
Per indicated horsepower hour ... pounds	3.23	3.07	2.93
Per electrical horsepower hour ... do	3.99	3.79	3.62
Dry fuel:			
Per indicated horsepower hour ... do	3.17	2.99	2.82
Per electrical horsepower hour ... do	3.91	3.69	3.48

[a] Run of mine.

Test 467 made on Renfrow briquets from briquetting test 176 (p. 87), which burned freely with short flame, 5.4 per cent black smoke, and very hot fire; briquets coking well and throwing off fragments of coke in ash during combustion; 39 per cent clinker, thin, metallic, red and black, brittle when cold; ash of dark-gray color, looked like coke.

The figures giving the pounds of water evaporated from and at a temperature of 212° F. per pound of dry fuel used represent the value of the coal for steaming. The first two tests give 8.93 and 9.45, or an average of 9.19, which compares very well with 10.545, the figure for the first-class steaming coal from Fayette, W. Va. (See

p. 37.) The figure for test 467 (10.04) represents the steaming value of briquets and strictly speaking should not be used in making comparisons with the results obtained from the raw coal.

Coking tests.—The results of the coking tests made on this coal are given below. [a]

Coking tests on Lower Kittanning coal from Wehrum.

[Run of mine, washed.]

		Test 185.	Test 188.
Size as used		Finely crushed.	Run of mine.
Duration of test	hours	61	54
Coal charged	pounds	9,750	12,460
Coke produced	do	5,779	8,144
	per cent	59.27	65.36
Breeze produced	pounds	262	332
	per cent	2.69	2.66
Total yield	do	61.96	68.02

Analyses of coal and coke.

	Test 185.		Test 188.	
	Coal.	Coke.	Coal.	Coke.
Moisture	7.19	0.56	4.53	0.57
Volatile matter	17.86	.32	18.56	.55
Fixed carbon	69.57	91.10	70.63	90.23
Ash	5.38	8.02	6.28	8.65
Sulphur	1.63	1.46	1.85	1.54

The coke resulting from the first test was of a dull-gray color, soft and dense, with high sulphur. The second test, with run-of-mine coal, produced a light-gray silvery coke, much better than the coke from the finely ground coal. In the coke from the second test, also, the sulphur is high. The yield in the second test was much better than that in the first. The coal mined at Nanty Glo from this bed has been tested in beehive ovens at Gallitzin. It produced coke of good structure but of dull appearance. As in the Wehrum samples, an insufficient amount of sulphur was volatilized. The Lackawanna Coal and Coke Company has experimented with its coal about Wehrum, but the washeries have long been closed and the results of the coking tests could not be learned. The Vinton Colliery Company has recently built a large by-product plant at Vintondale and a large part of the coal mined from colliery No. 6 in 1907 was coked in it.

[a] Bull. U. S. Geol. Survey No. 332, 1908, p. 203.

Producer-gas test.—The following producer-gas test was made:

Producer-gas test on Lower Kittanning coal from Wehrum.[a]

	Coal as fired.	Dry coal.	Combustible.
Coal consumed in producer per horsepower per hour.			
Per electrical horsepower:	*Pounds.*	*Pounds.*	*Pounds.*
Commercially available	1.29	1.26	1.12
Developed at switchboard	1.24	1.21	1.08
Per brake horsepower:			
Commercially available	1.10	1.07	.96
Developed at engine	1.05	1.03	.92
Equivalent used by producer plant.			
Per electrical horsepower:			
Commercially available	1.43	1.39	1.25
Developed at switchboard	1.37	1.34	1.20
Per brake horsepower:			
Commercially available	1.22	1.18	1.06
Developed at engine	1.17	1.14	1.02

[a] *Lump coal.*—Size as used: Over 1 inch, 7 per cent; ½ inch to 1 inch, 14 per cent; ¼ inch to ½ inch, 18 per cent; under ¼ inch, 61 per cent. Duration of test, 24 hours. Average electrical horsepower, 191.8. Average B. t. u. per cubic foot of gas, 144.4. Total coal fired, 5,700 pounds.

Analysis of gas by volume.[a]

Carbon dioxide (CO_2)	10.7
Carbon monoxide (CO)	17.2
Hydrogen (H_2)	15.8
Methane (CH_4)	2.2
Nitrogen (N_2)	53.8
Ethylene (C_2H_4)	.3

Washing tests.—Washing tests were made as follows. The figures indicate that finer crushing is advantageous. The loss of "good coal" (by which is meant all coal of a quality equal to or better than that of the washed coal) in the refuse will not exceed 2 per cent.

Float and sink tests of Lower Kittanning coal from Wehrum.

Number of test.	Size used (inch).	Specific gravity of solution used.	Percentage of float.		Sink (per cent).	Analysis.			
						Ash.		Sulphur.	
			To refuse.	To total sample.		Per cent.	Per cent reduction.	Per cent.	Per cent reduction.
On raw coal (preliminary):									
1	½	1.35	......	72	28	5.47	44	1.30	66
2	½	1.41	......	78	22	5.27	46	1.45	62
3	½	1.45	......	80	20	5.54	43	1.54	59
4	½	1.52	......	81	19	6.26	36	1.71	55
On refuse (float):[b]									
1	......	1.35	11.80	2.95	......	4.95	......	1.71	......
2	......	1.41	13.20	3.30	......	6.50	......	2.13	......
3	......	1.46	14.50	3.64	......	7.65	......	2.29	......
4	......	1.51	17.20	4.30	......	8.15	......	2.88	......

[a] For analyses of fuel used see analysis 27, p. 41.
[b] Duration of test, 2 hours. Size as used, through 1-inch screen. Jig used, special; speed, 70 revolutions per minute; stroke, 2½ inches. Raw coal, 20.37 tons; washed coal, 15.25 tons, or 75 per cent; refuse, 5.12 tons, or 25 per cent.

Analyses.

Sample tested.	Moisture.	Ash. Per cent.	Ash. Per cent reduction.	Sulphur. Per cent.	Sulphur. Per cent reduction.
Raw coal, car sample	3.13	9.81	....	3.77	....
Washed coal	6.46	5.38	45	1.53	59
Refuse	5.78	47.18	....	19.78	....

Briquetting tests.—Two briquetting tests were made of the coal. Test 176, with 7 per cent binder (water-gas pitch), gave satisfactory briquets, which were tough and easily handled without breaking when warm, but which were brittle when cold; they broke with characteristic smooth, glossy fracture, hard surface, and sharp edges. In test 184 the Wehrum coal was mixed with an approximately equal portion of anthracite graphitic coal from Cranston, near Providence, R. I. From this mixture excellent briquets were made with 6.25 per cent binder on the Renfrow (American) machine. Although the pitch used had a low melting point, the briquets handled well from the machine and piled without stocking. The outer surface was very hard and smooth and broke without crumbling, giving a smooth fracture and sharp edges.

Briquetting tests of coal from Wehrum.

[Water-gas pitch binder.]

	Test 176.[a]	Test 184.[b]
Details of manufacture:		
Machine used	Renf.	Renf.
Temperature of briquets..°F..	185	185
Binder—		
Laboratory No	4553	4543
Amount.........per cent..	7	6.25
Weight of—		
Fuel briquetted..pounds..	8,000	10,000
Briquets, average...do....	0.420	0.5
Heat value per pound—		
Fuel as received..B. t. u..	13,712	[c]13,712 [d]10,996
Fuel as fired........do....	13,702	12,793
Binder.............do....	16,969	16,966
Drop test (1-inch screen):		
Held...............per cent..	50.5	68.5
Passed.................do....	49.5	31.5

	Test 176.	Test 184.
Tumbler test (1-inch screen):		
Held...............per cent..	70.5	93.0
Passed (fines)..........do....	29.5	7.0
Fines through 10-mesh sieve ....per cent..	85.0	91.4
Weathering test:		
Time exposed..........days..	53	11
Condition	[e]A	[e]A
Water absorption:		
In 19 days..........per cent..	22.0	....
In 16 days..............do....	....	13.3
Average for first—		
4 days..............do....	4.05	....
5 days..............do....	....	1.90
Specific gravity (apparent).......	1.043	1.275

[a] Size as used: Over $\frac{1}{4}$ inch, 2.2 per cent; $\frac{1}{10}$ inch to $\frac{1}{4}$ inch, 6 per cent; $\frac{1}{20}$ inch to $\frac{1}{10}$ inch, 12 per cent; $\frac{1}{40}$ inch to $\frac{1}{20}$ inch, 19 per cent; through $\frac{1}{10}$ inch, 60.8 per cent.

[b] Size as used: Over $\frac{1}{4}$ inch, 0.8 per cent; $\frac{1}{10}$ inch to $\frac{1}{4}$ inch, 7 per cent; $\frac{1}{20}$ inch to $\frac{1}{10}$ inch, 15 per cent; $\frac{1}{40}$ inch to $\frac{1}{20}$ inch, 22.2 per cent; through $\frac{1}{40}$ inch, 55 per cent.

[c] Coal from Wehrum, Pa.

[d] Coal from Cranston, R. I.

[e] A=briquets in practically same condition as when put out. Surface shows no signs of erosion or pitting. Briquets hard with sharp edges and fracture same as that of new briquets. See Bull. U. S. Geol. Survey No. 332, 1908, p. 43.

Extraction analyses.

	Pitch.	Fuel.		Briquets.	
		Pennsylvania coal.	Rhode Island coal.	Test 176.	Test 184.
Laboratory No.	4543	4104	3141	....	4913
Air-drying loss .... per cent..	....	2.10	3.40	2.80	0.03
Extracted by CS_2:					
Air-dried .... do....	....	.79	.02	5.89	6.27
As received .... do....	99.66	.77	.02	5.72	6.25
Pitch in briquets, as received .... do....	....	....	....	5.02	5.91

Occurrence and physical character.—In its mode of occurrence the Lower Kittanning bed on Blacklick Creek strongly resembles in its main features the same coal in the districts along Conemaugh River. (See fig. 15.) The coal is made up of a bench from 3½ to 4 feet thick and of either one or two lower benches. In a few places both lower benches are missing (see sections 2, 5, and 6); the absence of both lower benches is, however, only local, for in the same mine the upper of the two has been observed at one place but has disappeared a short distance away. The lowest bench was not observed about South Fork or Johnstown but is persistent along Blacklick Creek. Here and there the main bench is underlain by bone. The middle bench is thin, averaging not more than 4 or 5 inches. The lower bench is 2 feet thick in places. The two shale partings inclosing the middle bench are thin, rarely exceeding a few inches in thickness. The analyses (see pp. 41–42) represent coal from the main bench; that from the middle thin bench is reported good but too thin to mine; and that from the lowest bench is high in ash and sulphur and usually too impure to ship. Below the lowest bench occurs a good deposit of clay, which has never been exploited along Blacklick Creek. The roof of the coal is either very firm shale or sandstone. The character of the roof, the irregularity of the floor, the general absence of clay veins, and the nongaseous nature of the coal are points in which it is similar to the Lower Kittanning (Miller) bed in the Conemaugh Valley. The coal is bright and lustrous, with a marked tendency to columnar cleavage.

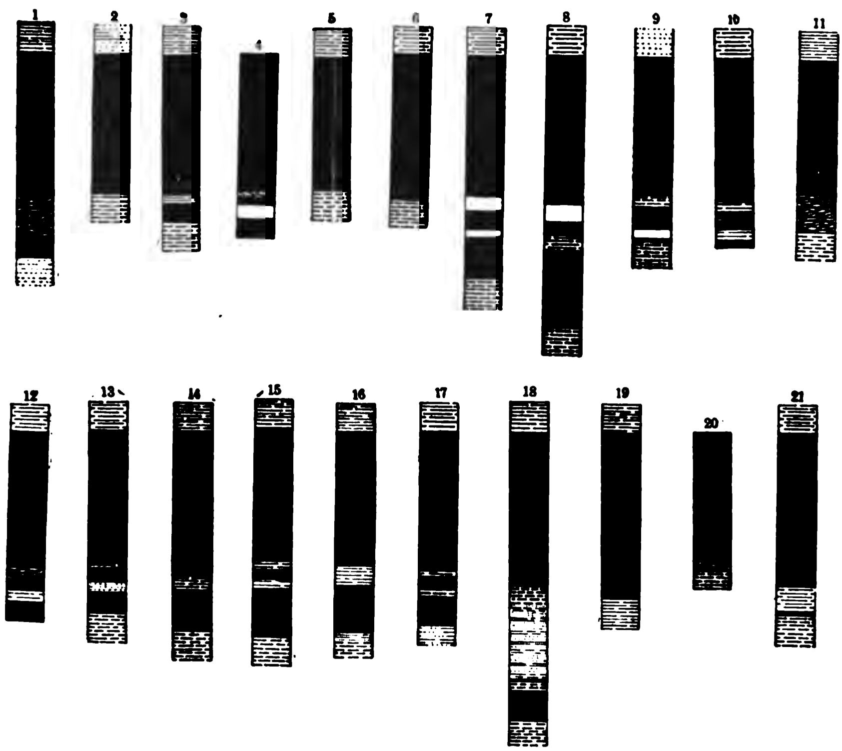

FIGURE 15.—Sections of the Lower Kittanning (Miller or B) coal in the Blacklick Creek district. Scale, 1 inch=5 feet.

1. Pennsylvania, Beech Creek and Eastern Coal Company No. 14, Nanty Glo.
2. Nanty Glo Coal Mining Company No. 1, Nanty Glo.
3. Lincoln Coal Company, Nanty Glo.
4. Ivory Hill Coal Mining Company, Nanty Glo.
5. Cardiff Coal Company, 5 miles north of Nanty Glo.
6. Country bank 1½ miles north of Nanty Glo.
7, 8. Commercial Coal Mining Company No. 3, 1½ miles east of Twin Rocks.
9. Big Bend Coal Mining Company, Nonpareil No. 1, Twin Rocks.
10. Big Bend Coal Mining Company, Big Bend Colliery No. 2, Twin Rocks.
11. Vinton Colliery Company No. 1, Vintondale.
12. Vinton Colliery Company No. 2, Vintondale.
13. Vinton Colliery Company No. 6, Vintondale.
14, 15. Vinton Colliery Company No. 3, Vintondale.
16. Vinton Colliery Company No. 5, Vintondale.
17. Exposure in railroad cut east of Vintondale.
18, 19. Lackawanna Coal and Coke Company No. 4, Wehrum.
20. Amos Rager, Rummel Run.
21. H. R. Dill, 1½ miles northwest of Dilltown.

LOWER ALLEGHENY COALS.

Along Blacklick Creek other coals are known which are below the Lower Kittanning bed. In the railroad cut near Twin Rocks these lower coals show, as they do also a short distance east of Weber. Just where the spur track turns in to the collieries of the Big Bend Coal Company at Twin Rocks the following section was measured:

Section of Brookville and Clarion coals (?) near Big Bend.

		Ft.	in.
Sandstone, massive.			
Coal, 10 inches...... / Parting, 6 inches... / Coal, 1 foot 6 inches / Parting, 4 inches... / Coal, 1 foot.........	Clarion (A′)?	4	2
Shale, black			8
Shale, sandy		2-3	
Coal (Brookville (A)?)			2
Clay		3-4	
Sandstone, massive.			

From the massive sandstones about the place where the section was made it is impossible to be absolutely sure that this coal is in the Allegheny. The massive sandstone overlying the coal in the cut may be traced northward along the nose where the river makes the big bend for some distance—in fact, so far as to make it fairly certain that it is an Allegheny sandstone and to corroborate the view that the coal whose section is given above probably corresponds to the lowest coal or coals in the Allegheny formation. One of these lower coals has been opened about 43 feet above the railroad tracks just back of Twin Rocks railroad station, but the bank is now fallen shut. The coal was reported as present only in patches and was known in the locality as the Three-foot seam or Sulphur vein.

The view that the coal in the cut near Twin Rocks is in the Allegheny formation and at its base is strengthened by observations made on the highway and along the railroad farther west, near Weber. Near Commercial No. 4 mine the massive sandstones may be observed close below the Lower Kittanning (B) coal, and at an estimated interval of 71 to 77 feet below are found two coals thought to correspond with the coals given in the foregoing section. These are regarded, on stratigraphic grounds, as Allegheny coals, and the massive sandstone is believed to be the Kittanning sandstone member. This heavy sandstone coming at the base of the Allegheny makes it difficult to conclude as to the position of the base of this formation, especially where the evidence has to be obtained at scattered points in different sections. This massive sandstone, however, is known to occur at other places in or near the quadrangle where the relations are plain and where there is no doubt as to its being in the Allegheny—for instance, south of the quadrangle, along Stony Creek.

Near Weber, as near Twin Rocks, the two coals occurring at the base of the Allegheny are too thin to be worked, each being less than a foot thick. The sections containing these two coals, regarded as the Brookville (A) and the Clarion (A′) coals, are given below. The first section was measured by Mr. Martin and the second and third by Mr. Phalen.

Sections of Brookville and Clarion coals near Weber.

1. Section on both sides of railroad cut.

	Ft.	in.
Sandstone, coarse grained, thin and thick bedded	19	8
Sandstone, with quartz crystals and iron ore	7	6
Coal, Clarion (A'?)		9
Fire clay, blocky, fine, sandy, fossiliferous	2	6
Sandstone, fine grayish	1	9½
Sandstone, blue-black, shaly		7½
Sandstone, fine grained, grayish		6
Shale, bluish black, with limestone nodules	4	6
Coal, Brookville (A?)		2½
Clay, grayish	4	6+

2. Section on north side of cut.

	Ft.	in.
Sandstone.		
Coal (bony in middle), Clarion (A')		9
Fire clay, gravelly, sandy, almost sandstone. Contains abundant organic impressions (fossil imprints), but they are very poor.	5	
Shale, drab or dark gray	4	6
Coal, Brookville (A)		1¾
Clay		6+

3. Section on south side of cut.

	Ft.	in.
Sandstone.		
Coal, Clarion (A')		8-9
Sandstone, gnarly, or sandy fire clay with plant impressions	6	6
Shale, dark, with concretions	4	9
Coal, Brookville (A)		2
Shales, dark, irregularly bedded, upper part resembling fire clay.	4	

The dip from the south to the north side of the track is marked, even for so short a distance.

WINDBER DISTRICT.

EXTENT.

The Windber district of this report includes the territory about the town of Windber, situated within the Johnstown quadrangle.

GEOLOGIC POSITION OF THE COALS.

All the workable coals in this district are found in the Allegheny formation, which is above drainage level in all the hills surrounding Windber and Scalp Level. Of these coals, only the Lower Kittanning is now worked, but higher coals are known to be valuable.

The usual main coals of the Allegheny formation are represented in this district—that is, the Upper and Lower Freeport and the Upper, Middle, and Lower Kittanning coals. These coals are also visible in the road sections in the surrounding hills. The distance between the highest and lowest of the five beds varies from 180 feet to about 210 feet, and, as usual, the Upper Kittanning bed occurs about midway between. A section of the lower part of the

Allegheny was hand leveled by W. C. Phalen at Scalp Level, from the point where the trolley line crosses Paint Creek. This section is as follows:

Section of lower Allegheny rocks at Scalp Level, Somerset County, Pa.

	Ft.	in.
Sandstone débris.		
Coal		10–12
Clay	3	
Shale, sandy	5	
Shale, blue	15	
Coal		3–4
Sandstone, gnarly	1	
Concealed, but with 1 foot of Lower Kittanning coal showing at top (railroad level)	16	6
Shale, black	5	
Shale, sandy	10	
Shale	5	
Shale, débris	20	
Coal, 10 inches; Shale, 4 inches; Bone, 6 inches; Coal, 6 inches (Brookville or Clarion)	2	2
Concealed	10	
Sandstone, Pottsville	6+	

According to these measurements, the interval from the top of the Pottsville to the top of the Lower Kittanning (B) coal is about 70 feet, and the single coal which shows in the section may be the equivalent of the Brookville or Clarion beds. At Scalp Level, where Paint Creek passes over bluffs of the Pottsville formation, D'Invilliers [a] noted a thin seam of coal 14 to 18 inches thick outcropping just above the water. This bed was not observed and may possibly be the representative of the other of these lower coals.

On the assumption that the average thickness of the Allegheny from the Lower Kittanning bed to the Upper Freeport, near Windber, is 180 feet and the interval from the top of the Pottsville to the Lower Kittanning is about 75 feet, the thickness of the Allegheny in this district is about 250 feet.

ALLEGHENY COALS.

UPPER FREEPORT COAL.

The Upper Freeport (E) coal is the highest of the important coals outcropping in the hills surrounding Windber. It lies, according to barometric measurements, about 170 to 180 feet above the Lower Kittanning coal, and this interval remains fairly constant as far to the northeast as Elton, where drillings show it to be about 175 feet. Still farther northeast, toward South Fork of Conemaugh River, the inter-

[a] Summary Final Rept. Pennsylvania Geol. Survey, vol. 3, pt. 2, 1895, p. 2248.

val increases to 200 feet. West of Stony Creek, in Somerset County, according to the only available information, which has been procured from diamond-drill records, the interval is about 200 feet.

Little definite information was obtained as to the thickness of the Upper Freeport coal in this district, as no openings were located on it. The diamond-drill records northeast of Windber all indicate that it is workable, containing on an average about 3 feet of coal. It is known to be persistent—a fact which, in connection with a thickness of 3 feet, seems to place it among the future sources of supply in this region.

LOWER FREEPORT (D) COAL.

The Lower Freeport (D) coal is also persistent in this district; but little is known about it except from data furnished from drillings. Some of the records from points northeast of Windber show it to be in places 3 feet thick; others show less promising sections. It is possible that this bed may be valuable in the future; but the data obtained are insufficient to afford a basis for a positive opinion.

UPPER KITTANNING (C′) COAL.

The Upper Kittanning (Cement or C′) coal about Windber lies practically midway between the Upper Freeport and Lower Kittanning beds. This is one of the most valuable coals about Wind-

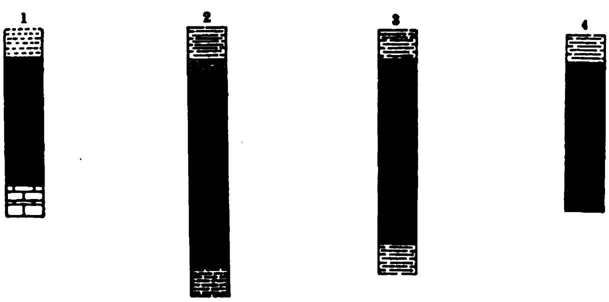

FIGURE 16.—Sections of the Upper Kittanning (Cement or C′) coal in the Windber district. 1, Baltimore and Ohio Railroad south of quadrangle; 2, Stony Creek west of Ingleside; 3, east of Walsall; 4, head of Walsall Creek. Scale, 1 inch = 5 feet.

ber. Though it is not worked on a commercial scale, something is known at least of its physical character from prospects on it in the region north of Windber, within the limits of the Johnstown quadrangle. In the description of this coal in the Johnstown district it was stated that it increased in thickness along Stony Creek, southward from Moxhom. As a matter of fact, the unusual thickness of 5 feet 6 inches prevails generally north of Windber; 6 feet has been measured one-half mile north of Eureka No. 37 and 5 feet 5 inches 1 mile north of the same mine. In both places the roof was black shale. (See also fig. 16.)

Section 1 in figure 16 can not be regarded as strictly in the Windber district, as it is on the west flank of the Ebensburg (Viaduct) axis, some miles above the mouth of Paint Creek. Sections 2 and 3 are taken from country banks near Windber. Section 4 may possibly be incomplete, as two sections measured about half a mile south and less than a mile west show very nearly 5 feet of coal in one and more than 5 feet in the other.

Enough is known of the coal in this district to be certain that it is of workable thickness. It may not average as thick as the above sections indicate, but an average of 4 to 5 feet in the hills north of Windber is probably a conservative estimate. Its quality is probably equal to that of the coal mined from this bed near Johnstown. (See p. 40.) In places the upper part of the coal bed is bony and will have to be discarded in mining. The roof is generally very firm shale.

MIDDLE KITTANNING COAL.

The next lower coal, the Middle Kittanning (C), is 25 to 30 feet above the Lower Kittanning bed. A few of the diamond-drill records to the northeast of Windber show nearly 3 feet of coal in this bed. This thickness is exceptional. The coal may prove valuable in this district, but not enough is known about it to form a positive opinion.

LOWER KITTANNING COAL.

Name and position.—The Lower Kittanning (Miller or B) coal in the Windber district occurs, as stated above, at an interval of about 170 to 200 feet below the Upper Freeport coal along the southern edge of the quadrangle. Immediately about Windber the interval is somewhat nearer the former than the latter figure. The coal outcrops well down in the hills about the town, permitting the operations to be conducted from the outcrop by drifts.

Extent and development.—The coal appears above drainage level on the eastern flank of the Ebensburg (Viaduct) anticline where this fold approaches the Wilmore Basin, near the southern edge of the quadrangle, and is present in the hills along Paint Creek westward to Stony Creek. The coal is above drainage level northward for some distance on Stony Creek, where the dip to the Johnstown Basin carries it below water level.

The operations on this bed of coal in the portion of the Windber district in this quadrangle are but a small part of the coal industry around Windber. As noted above, only two operations are conducted wholly within the Johnstown area—namely, Eureka Nos. 37 and 40.

Chemical character.—Analyses Nos. 30 to 32, pages 41–42, indicate the composition of the Lower Kittanning (Miller) coal about Windber. The analyses show its carbon content to be among the highest in the area, with a comparatively small amount of sulphur and ash.

Occurrence and physical character.—The sections in figure 17 illustrate the general section of the coal in the Windber district. The first two are the more representative, as they are more complete, showing the under coal characteristic of the Lower Kittanning (Miller) bed.

The main bench averages between 3½ and 4 feet of coal. A small rider, averaging 3 to 4 inches in thickness but varying from 1 to 14 inches, occurs from 3½ to 4 feet above the top of the main bench; it is noted in the Scalp Level section given on page 92. There is also usually present an under coal lying from 3 inches to 2 feet below the

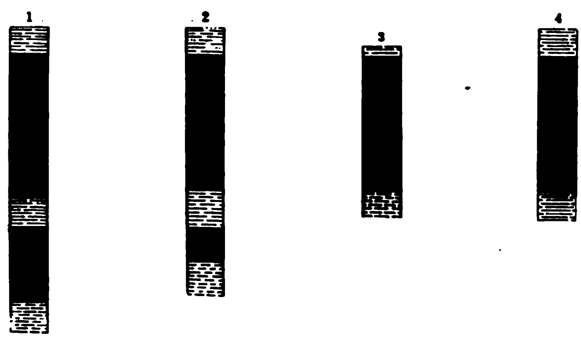

FIGURE 17.—Sections of the Lower Kittanning (Miller or B) coal in the Windber district. 1, Baltimore and Ohio Railroad south of quadrangle; 2, Berwind-White Coal Mining Company, Eureka No. 37, Windber; 3, near south edge of quadrangle; 4, near Walsall. Scale, 1 inch = 5 feet.

main bench. This under coal ranges from 3 to 18 inches in thickness and may be very regular.

The roof is excellent and is either sandstone or sandy shale. It requires little or no timbering except where broken through. The partings in the coal are the usual "sulphur" lentils or balls, which are easily separated from the coal. Rolls are numerous and here and there the coal is completely pinched out. In places the slickensided surfaces associated with thin coal indicate movement akin to true faulting. The under clay is not worked in any of the mines, so far as known. The coal in the main bench is of the lustrous columnar variety.

LOWER ALLEGHENY COALS.

Though lower coals occur about Windber, they are too thin to be worked so far as known. Section showing the relations of these lower Allegheny coals are given on page 24.

CONEMAUGH FURNACE DISTRICT.

EXTENT.

Along the west edge of the quadrangle, in the valley of Conemaugh River, the lower part of the Allegheny is brought down to drainage level by the steep dips along the western flank of the Laurel Ridge anticline. As the Allegheny or coal-bearing formation outcrops only along the river, the active mines are confined to the immediate river valley, and the district is small. Within the Johnstown area there are but two active mines—that of the Johnstown Coal Company and that of the Nineveh Coal Company. Both these concerns are working on the Lower Kittanning (Miller) bed. The dips carry this coal below drainage level just beyond the confines of the quadrangle, and farther west, in the town of Seward, it lies at a depth of 130 feet, as shown by the shaft of the Seward Coal Company.

ALLEGHENY COALS.

UPPER COALS.

But little definite information can be given regarding the three highest coals in the Allegheny formation in this part of the quadrangle, for the reason that they have not been worked even on a small scale and few openings on them were found. It is known, however, that they are present in the hills north of Conemaugh River, outcropping along Trout Run, on which the Upper Freeport bloom was discovered. At this place a small opening, believed to be on the Upper Kittanning coal, showed the following section:

Section of Upper Kittanning coal on Trout Run.

	Ft.	In.
Massive shale roof.		
Coal	1	
Bony		4
Coal	2	3½+

The Middle Kittanning is fairly persistent in this district and occurs about 40 feet above the Lower Kittanning (Miller) bed. Near Cramer this bed measured as follows:

Section of Middle Kittanning (C) coal near Cramer.

	Ft.	In.
Shale		6
Coal	1	8
Bony		2
Coal		11
Clay.		

About Seward this coal measures 2 feet 6 inches. At Seward also the Lower Freeport (D) coal is reported as being about 2 feet thick, capped by 8 to 12 feet of shales mixed with sandstone slabs and underlain by 7 feet of bluish massive shales. The overlying shales are used in the manufacture of red building brick.

LOWER KITTANNING (B) COAL.

Extent and development.—The only coal of commercial importance around Conemaugh Furnace at present is the Lower Kittanning (Miller) bed, and, as stated above, there are but two mines at which this coal is worked—that of the Johnstown Coal Company, on the north side of Conemaugh River, and that of the Nineveh Coal Company, on the south side of the river and on the main line of the Pennsylvania Railroad. The coal here lies about 65 to 70 feet above the top of the Pottsville formation. Farther west the coal goes below drainage level and is mined by shaft near Seward by the Seward Coal Company.

Chemical character.—A sample carload of coal from this bed, collected and shipped by J. W. Groves, of the United States Geological Survey, from a point on the Pennsylvania Railroad 1½ miles east of Seward, Westmoreland County, has been subjected to steaming, washing, coking, and briquetting tests,[a] so that the character and behavior of the coal in this part of the quadrangle are known. Two mine samples were also collected for chemical analysis. The results of the chemical analyses are given on pages 41–42 (Nos. 33–35) and below:

Chemical analyses of Lower Kittanning coal from Conemaugh Furnace district.

	Steaming tests.[a]		Briquetting tests.[b]	
	512.	514.	198.	213.
Laboratory number	4726	4713	4769	4885
Proximate:				
Moisture	3.50	2.79	6.16	1.23
Volatile matter	19.98	21.11	19.23	20.58
Fixed carbon	67.71	67.79	64.38	67.74
Ash	8.81	8.31	10.23	10.45
Sulphur	1.59	1.91	2.68	2.98
Ultimate:				
Hydrogen	4.39	4.42	4.20	4.56
Carbon	81.06	80.25	78.12	79.21
Nitrogen	1.06	1.09	1.09	1.12
Oxygen	2.72	3.73	2.83	1.51
Ash	9.13	8.55	10.90	10.58
Sulphur	1.64	1.96	2.86	3.02

[a] Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.
[b] Proximate analysis of fuel as received; ultimate analysis on dry basis.

Only the proximate analyses are of interest in this connection, and these need but little comment. They show the usual high carbon characteristic of this coal in the Johnstown quadrangle, together with low volatile matter. The moisture is about the same as usual for this coal, though perhaps a trifle higher. Ash and sulphur are both higher than the average for this coal in the rest of the area.

[a] Bull. U. S. Geol. Survey No. 332, 1908, pp. 216 et seq.

Steaming tests.—The steaming tests were not made on the coal itself but on briquets made from it, and the results are given in the table below. The weights of water evaporated from and at a temperature of 212° F. per pound of dry fuel used—9.65 pounds in test 512 and 8.14 pounds in test 514—indicate the standing of briquets made from this coal. The results should be compared with the results with first-class steaming coals given on page 37.

Steaming tests on Lower Kittanning coal from the Conemaugh Furnace district.

	Test 512.[a]	Test 514.[b]
Duration of test....hours..	7.77	7.93
Heating value of fuel....B. t. u. per pound of dry fuel..	14,495	14,382
Force of draft:		
Under stack damper....inch of water..	0.93	0.93
Above fire....do....	.19	.23
Dry fuel used per square foot of grate surface per hour....pounds..	19.93	27.52
Equivalent water evaporated per square foot of water-heating surface per hour..do....	3.84	4.47
Percentage of rated horsepower of boiler developed....	107.7	125.3
Water apparently evaporated per pound of fuel as fired....pounds..	7.70	6.54
Water evaporated from and at 212° F.:		
Per pound of fuel as fired....do....	9.32	7.91
Per pound of dry fuel....do....	9.65	8.14
Per pound of combustible....do....	10.76	9.06
Efficiency of boiler, including grate....per cent..	64.29	54.66
Fuel as fired:		
Per indicated horsepower hour....pounds..	3.03	3.58
Per electrical horsepower hour....do....	3.75	4.41
Dry fuel:		
Per indicated horsepower hour....do....	2.93	3.47
Per electrical horsepower hour....do....	3.62	4.29

[a] Equal weights of briquets made from washed coal (briquetting tests 215 and 216, p. 100).
[b] Equal weights of briquets (briquetting tests 208 and 209, p. 100).

Test 512 on briquets from tests 215 and 216 (equal weights); briquets burned freely, with intense heat and no smoke; 31 per cent clinker. Test 514 on briquets from tests 208 and 209 (equal weights); briquets burned freely, with intense heat and no smoke; 50 per cent clinker.

Coking tests.—The results of the coking tests on this coal are given below, together with analyses of the coal and resulting coke.

Coking tests on Lower Kittanning coal from Conemaugh Furnace district.

[Run-of-mine coal, finely crushed.]

	Test 179 (raw).	Test 182 (washed).
Duration of test....hours..	68	78
Coal charged....pounds..	13,070	11,760
Coke produced....do....	8,129	7,350
Coke produced....per cent..	62.20	62.50
Breeze produced....pounds...	420	529
Breeze produced....per cent..	3.21	4.50
Total yield....do....	65.41	67.00

Test 179 yielded soft, dense coke light gray and silvery in color, with high ash and sulphur. Test 182 yielded soft, dense coke gray in color. Ash and sulphur were reduced by washing. There was no improvement in physical appearance.

Analyses.

	Test 179.		Test 182.	
	Coal.	Coke.	Coal.	Coke.
Moisture	3.91	0.30	6.30	0.51
Volatile matter	16.35	.28	17.04	.58
Fixed carbon	68.30	84.95	69.58	89.85
Ash	11.44	14.47	7.08	9.06
Sulphur	2.78	2.31	1.34	1.11

Washing tests.—Results of washing tests are given below. The figures indicate that finer crushing is advantageous. The loss of "good coal" (by which is meant all coal of a quality equal to or better than that of the washed coal) in the refuse will not exceed 2 per cent.

Float and sink tests on Lower Kittanning coal from Conemaugh Furnace district.[a]

Number of test.	Size used (inch).	Specific gravity of solution used.	Percentage of float.		Sink (per cent).	Analyses.			
						Ash.		Sulphur.	
			To refuse.	To total sample.		Per cent.	Per cent reduction.	Per cent.	Per cent reduction.
On raw coal (preliminary):									
1	[illegible]	1.35	....	83	17	4.95	53	0.93	67
2	[illegible]	1.42	....	88	12	5.66	46	1.24	57
3	[illegible]	1.45	....	88	12	4.72	55	1.02	64
4	[illegible]	1.52	....	89	11	6.07	42	1.09	62
On refuse (float):									
1	......	1.35	17.20	3.91	....	5.42	....	1.69	....
2	......	1.41	18.50	4.20	....	5.69	....	1.69	....
3	......	1.45	19.88	4.51	....	6.45	....	2.15	....
4	......	1.53	20.20	4.59	....	7.89	....	2.08	....

[a] Duration of test, 2¾ hours. Size as used, through 1-inch screen. Jig used, special; speed, 70 revolutions per minute; stroke, 2½ inches. Raw coal, 22.21 tons; washed coal, 17.25 tons, 78 per cent; refuse, 4.96 tons, 22 per cent.

Analyses.

Sample tested.	Moisture.	Ash.		Sulphur.	
		Per cent.	Per cent reduction.	Per cent.	Per cent reduction.
Raw coal, car sample	4.00	10.54	....	2.85	....
Washed coal	6.48	6.76	36	1.30	54
Refuse	10.21	46.25	....	17.40	....

Briquetting tests.—Seven briquetting tests were made, three on raw and four on washed coal. Briquets from both the English and the Renfrow (American) machines had similar appearance, with smooth, hard surface, were very brittle, and broke with a glossy fracture and sharp edges. The percentage of binder (water-gas pitch) seemed to have little effect on brittleness, although Renfrow briquets with 8 per cent binder were handled with less breakage. There was no noticeable difference between the briquets made from raw and those from washed coal.

For analyses of coal used in briquets see page 97 (those from briquetting tests 208 and 209 under steaming test 514; from briquetting tests 212, 215, and 216 under steaming test 512).

Briquetting tests on run-of-mine coal from Conemaugh Furnace district.

[Water-gas pitch binder.]

	Test 198.	Test 208.	Test 209.	Test 212.	Test 213.	Test 215.	Test 216.
Details of manufacture:							
Machine used	Eng.	Renf.	Renf.	Renf.	Renf.	Eng.	Eng.
Temperature of briquets	158	158	158	158	158	176	176
Binder—							
Laboratory number	4683	4683	4683	4683	4683	4683	4683
Amount per cent	6	7	8	7	8	6	7
Weight of—							
Fuel briquetted pounds	3,200	4,500	8,000	6,500	6,500	6,400	3,300
Briquets, average do	3.52	0.451	0.457	0.427	0.458	3.63	3.44
Heat value per pound—							
Fuel as received B. t. u.	13,347	13,347	13,347	14,639	14,639	14,639	14,639
Fuel as fired do	13,198	13,981	13,981	....	13,896	13,988	13,988
Binder do	16,637	16,637	16,637	16,637	16,637	16,637	16,637
Drop test (1-inch screen):							
Held per cent	74.8	19.5	26.0	23.0	19.5	74.6	71.9
Passed do	25.2	80.5	74.0	77.0	80.5	25.4	28.1
Tumbler test (1-inch screen):							
Held do	71.0	54.0	61.5	67.0	64.0	74.0	70.5
Passed (fines) do	29.0	46.0	38.5	33.0	36.0	26.0	29.5
Fines through 10-mesh sieve do	65.4	86.8	86.4	91.6	87.3	63.2	70.4
Water absorption:							
In 13 days do	14.5	15.5	15.0	19.0	14.5	9.5	11.0
Average for first 5 days do	2.34	2.78	2.66	3.1	2.50	1.56	1.56
Specific gravity (apparent)	1.141	1.11	1.127	1.043	1.144	1.148	1.121

Tests 198, 208, and 209. Size used: Over ½ inch, 0.8 per cent; 1/10 inch to ½ inch, 3.6 per cent; 1/20 inch to 1/10 inch, 11.2 per cent; 1/40 inch to 1/20 inch, 27 per cent; through 1/40 inch, 57.4 per cent.

Tests 212, 213, 215, and 216 (on washed coal). Size as used: Over ½ inch, 0.8 per cent; 1/10 inch to ½ inch, 4.8 per cent; 1/20 inch to 1/10 inch, 16 per cent; 1/40 inch to 1/20 inch, 26 per cent; through 1/40 inch, 52.4 per cent.

Extraction analyses.

	Pitch.	Fuel.	Briquets.			
			Test 198.	Tests 208, 209.	Test 213.	Tests 215, 216.
Laboratory No	4683	4498	4769	4713	4885	4726
Air-drying loss per cent	....	3.10	5.50	2.00	0.60	3.10
Extracted by CS_2:						
Air-dried do	....	1.02	5.60	6.86	8.03	6.90
As received do	89.31	.99	5.29	6.72	7.98	6.61
Pitch in briquets as received do	....	....	5.00	6.49	7.92	6.37

Occurrence and physical character.—The sections in figure 18 indicate the thickness of the Lower Kittanning coal, its under benches, and the character of its roof and floor in the Conemaugh Furnace

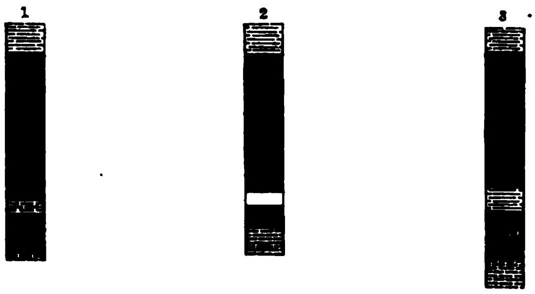

FIGURE 18.—Sections of the Lower Kittanning (Miller or B) coal in the Conemaugh Furnace district. 1, 2, Johnstown Coal Company, north of Conemaugh River; 3, Nineveh Coal Company, Seward mine, south bank of Conemaugh River. Scale, 1 inch = 5 feet.

district. In addition to the sections shown in the figure, the following were measured:

Section of Lower Kittanning coal on Laurel Ridge, near Cramer.

	Ft.	in.
Shale roof.		
Coal	3	7
Shale		6
Coal	1 to 1	8
Fire clay.		

Section of Lower Kittanning coal at mine of Seward Coal Company, Seward.

	Ft.	in.
Shale roof.		
Coal	3	3
Shale or clay		6
Coal	1	
Clay		6
Coal		6
Fire clay, hard	1	
Clay, soft (reported)	1	4

The coal near Conemaugh Furnace and Seward is comparable in every way with the corresponding coal as mined farther east near Johnstown, South Fork, Blacklick Creek, and Windber. In this particular district the bed was measured and studied in three mines and seen at one country bank. The main bench ranges from 3 feet 3 inches to 3 feet 9 inches. Below this, one and in places two lower benches are found. The first ranges in thickness from 6 to 20 inches and is separated from the main bench by a shale parting usually not more than 6 inches thick; this bench is used at Seward by the brick company to burn bricks. The second lower bench is about 6 inches thick, and the underlying clay is reported as thick as 17 feet, only 6 feet of which is considered of brickmaking grade. The roof of the coal is firm shale and the usual rolls in the floor are present.

COAL MINING.

Two general systems of working coal were employed in the Johnstown quadrangle when this work was done—the room and pillar system and the long-wall system. The former is in most common use, but two of the mines along Blacklick Creek (Nos. 1 and 3 of the Vinton Colliery Company) have used the long-wall system.

ROOM AND PILLAR SYSTEM.

General description.—The diagram or plan of the workings of one of the mines in the quadrangle given in figure 19 conveys some idea of the methods generally employed in the room and pillar method of mining coal.

Most of the mines in the quadrangle are drift mines and work coal which averages between 3 and 4 feet in thickness. For this reason, in the headings where hauling is done the roof is generally removed so as to allow between 5 and 5½ feet above the rail or nearly 6 feet in the clear. The main heading is usually driven straight and is cut through rolls, which are very common in the Lower Kittanning (Miller) coal, the most important bed of the area. If the rolls are too pronounced, however, the main heading may be curved around them.

The main entry or heading is usually run about 10 feet wide; in some mines it is as narrow as 9 feet and in a few as wide as 12 feet; in still others the width of the main headings ranges from 18 to 25 feet, but in such mines the rock is gobbed underground. Wide headings are not usual. The main airways appear to be about as wide as the main headings, and the pillar left between the two averages about 50 feet.

Cross or side headings are run from the main headings either at a considerable inclination or at right angles. The width of the cross headings varies but is commonly about 15 to 18 feet. One mine at South Fork reported cross headings only 7 to 8 feet wide. A few mines near Johnstown reported cross headings as broad as 21 and 24 feet, but here it is possible that much of the rock may be gobbed underground. About South Fork some of the larger mines reported cross headings 550 feet apart. In turning rooms from the cross headings the turn may be about 9 feet long and 15 feet wide, but the practice may vary considerably from these figures.

The dimensions of rooms vary within narrow limits. The width ranges from 21 to 40 feet; 24-foot rooms are very common, but those in excess of 30 feet are rare. About South Fork the roof of the Lower Kittanning (Miller) coal has caused trouble in places, and some rooms have been lost on account of running them too wide; in the mines where this difficulty was encountered a 21-foot room with 15 to 20 foot pillars has given the best satisfaction. The length of the

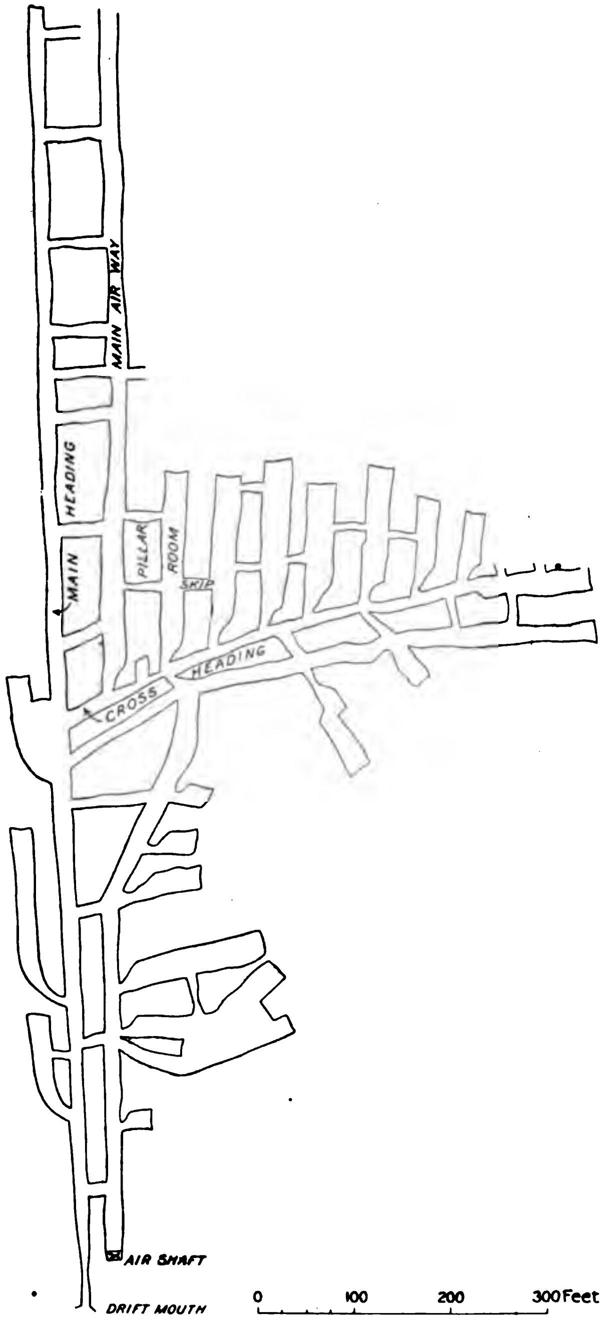

FIGURE 19.—Diagram illustrating room and pillar method of mining in Johnstown quadrangle.

rooms in the larger mines is usually 300 feet, but ranges from 225 to 360 feet, the latter length being fairly common near South Fork and along Blacklick Creek. In many of the smaller mines the length of rooms is less than 100 feet.

The width of pillars between rooms is generally 30 feet, but in some of the mines where the covering is unusually heavy more pillar has to be left, and at South Fork some of the larger mines report 34 to 36 foot pillars. As stated above, a 15 to 20 foot pillar gives the best satisfaction in certain mines. Pillars 27, 24, and 21 feet wide are also used at a few mines. A 60-foot pillar was reported from a couple of mines. A "skip" is a crosscut between two adjacent rooms. Its length, of course, is the width of a pillar; its width varies from 10 to 20 feet. Pillars are worked back from the room face within 60 feet of the cross headings until all the rooms in the cross headings are worked out. The roof is allowed to cave after the coal is worked out.

The methods of ventilation, drainage, and haulage of coal to the surface, together with the mining methods employed, vary widely. Some of the mines in the quadrangle are among the largest in the State and employ hundreds of men. Such mines have extensive underground workings and employ the most elaborate and expensive systems to insure the safety of the lives of the men and the cheapest and most expeditious means of transferring coal from mining breasts to coal cars. At Windber, for instance, machine mining is practiced almost altogether at Eureka No. 37, compressed-air machines being used. Hauling is done by electricity and ventilation by fans. The drainage is natural and by pump. Of Eureka No. 40 mine, which is the latest in the Windber territory, J. T. Evans, mining inspector of the sixth bituminous district of Pennsylvania, says:[a] "It will be the model mine of the district."

Ventilation.—Ventilation is effected by natural methods, furnace and stack, or fan. In the smaller mines the first two methods are in common use, but in the larger mines fan ventilation has to be employed. The variety of the fans used is great; the size of fan and the number of revolutions made per minute depend entirely on local coditions. The motive power used in driving the fans is compressed air, electricity, steam, etc.

Drainage.—Drainage is either natural or artificial. In most of the smaller mines and in some of the larger workings natural drainage is used. Artificial drainage is accomplished by pumps driven by compressed air, steam, or electricity; hand pumps are also used.

Haulage.—In the smaller mines both hand haulage and mule haulage are employed. In the larger mines mule haulage is used almost exclusively as an auxiliary; the mules haul the loaded mine

[a] Rept. Pennsylvania Dept. Mines, pt. 2, 1906, p. 377.

cars to the foot of slopes or planes or to the electric tramways, and the loaded cars are hauled out by wire ropes or electric locomotives. The overhead-trolley system is in common use and at South Fork the third-rail system is used in one of the mines.

Tipples are of various makes. The old-fashioned cradle tipple is still the most popular, but an automatic dump is used at some of the larger mines at South Fork and on Blacklick Creek, a crossover patent in at least two mines on Blacklick Creek, and a kind of rotary tipple at one mine in the Blacklick Creek district. At the Conemaugh slope the coal is dumped at the mine mouth into buckets of 1,000 pounds capacity, which are then conveyed by electric power from the north side of Conemaugh River over the Pennsylvania Railroad to the Franklin plant of the Cambria Steel Company.

Mining methods.—The mining methods employed in the Johnstown quadrangle are hand or pick mining and machine mining. In some of the larger mines machines are used almost exclusively, but as a general thing a combination of pick and machine mining is found more satisfactory.

LONG-WALL SYSTEM.

The conveyor method of the long-wall system of mining coal has been used at collieries Nos. 1 and 3 of the Vinton Colliery Company at Vintondale, in the Blacklick Creek district (fig. 20). It has been abandoned for some years in this district. The long-wall system is the one most commonly used in the coal mines of Europe, where it is regarded as being much more economical of the coal than the room and pillar method. For this reason it was recommended in the report to the Secretary of the Interior by Messrs. Watteyne, Meissner and Desborough,[a] the three foreign experts recently selected for the investigation of mine explosions in the United States. The long-wall system has a number of modifications, that used in the Blacklick Creek district and commonly referred to as the conveyor method being one of them. Figures 21 and 22 illustrate the method as formerly practiced at Vintondale. The coal bed worked is the Lower Kittanning (Miller or B) bed. It usually runs 3 feet 6 inches thick near Vintondale, and its maximum and minimum thickness may be taken as 3 feet 10 inches and 3 feet 3 inches, respectively. Below the main bench, from which it is separated by 8 to 10 inches of shale, is a coal ranging from 2 to 10 inches in thickness. The roof of the coal is hard shale and is a most excellent cover, though it has marked slips or crevices. The coal is bound very tightly to both roof and floor. The average thickness of the cover is about 180 to 200 feet. The territory of the mines is long and narrow, and this, together with the

[a] Bull. U. S. Geol. Survey No. 369, 1908, p. 6.

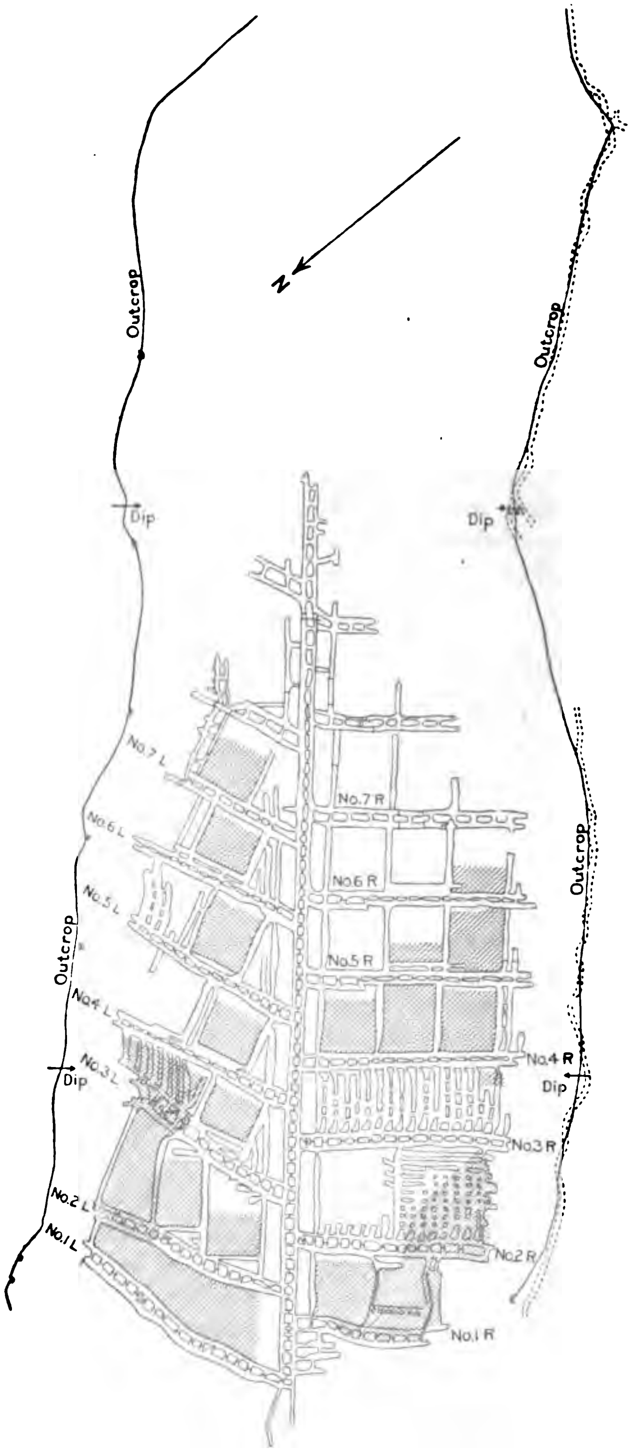

FIGURE 20.—Plan showing long-wall method of mining as employed at Vinton collieries Nos. 1 and 3, Vir

heavy pitch of the coal (see Pl. I), makes the successful working of the bed by the room and pillar method difficult.[a]

The long-wall method as first practiced at Vintondale differs somewhat from the method used there later. At the beginning of the operations in this region the faces of the coal were worked by passing the mine cars at one end of the face, along the face, and out at the opposite end when loaded. The results were only fair, as the roof and the steep grades both gave trouble. In the other mines working at Vintondale at this time no marked slips or cracks in the roof had been noticed and it was naturally inferred that these conditions would prevail generally; but after the long-wall faces had been in

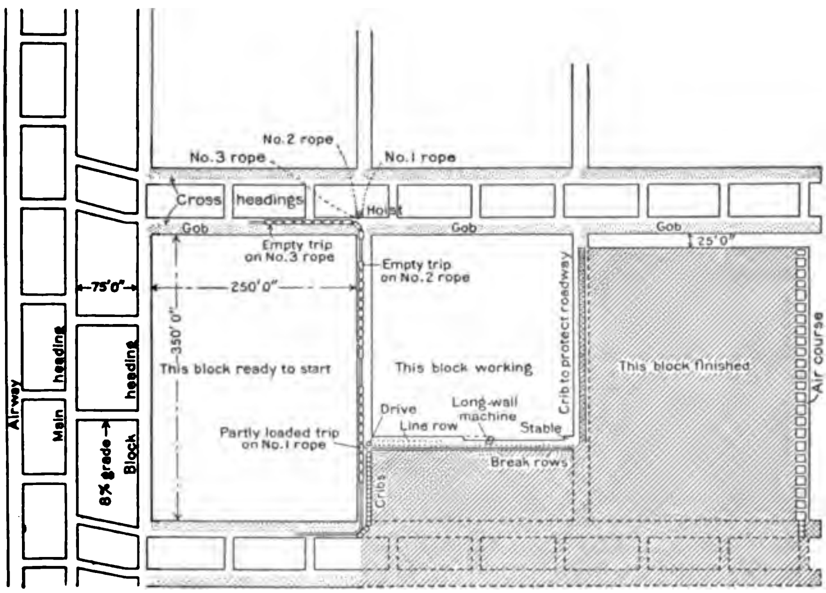

FIGURE 21.—Plan of workings, single long-wall conveyor system. (From an article by J. I. Thomas in Mines and Minerals, November, 1907, pp. 200-203. Reproduced by permission.)

operation for some time marked slips were encountered almost exactly in line with the face of the coal, and it was found very difficult to keep the roadway open when these slips occurred at the working face.

Another reason for abandoning this method of working was the difficulty of controlling mine cars on the heavy grades. Not only wrecks but delays were caused by mine cars getting beyond the working faces. If the roof conditions had been more favorable, the proposed method of working would have made, with slight modifications, an excellent arrangement for the use of the conveyor system.[b]

[a] A description of the method of mining the coal in this region was read by Mr. Clarence R. Claghorn at the February, 1900, meeting of the North of England Institute of Mining and Mechanical Engineers (Trans. Inst. Min. Eng., vol. 18, 1900, pp. 351 et seq.).

[b] Ware, R. G., Trans. Inst. Min. Eng., vol. 29, 1906, pp. 462-474.

To overcome the delays and difficulties, C. R. Claghorn proposed that a conveyor should be installed along the long-wall faces and that the mine cars should be run on a semipermanent road under the head end of the conveyor and there loaded instead of being passed along the face. From the first the conveyor was a success.

The following descriptions of the working methods at Vintondale are by Mr. J. I. Thomas, assistant superintendent of the Vinton collieries[a] when the field work on the report was done:

The block work, which is a modification of long-wall mining, was first started in the No. 3 mine of this company seven years ago. At the outset cars were run around the working face and loaded. This method brought only fair results owing to the necessity of using small cars, steep grades, and difficulty in keeping roadways open. Arrangements were then made for the placing of a conveyor along the face, allowing the cars to be run under the head end to be loaded.

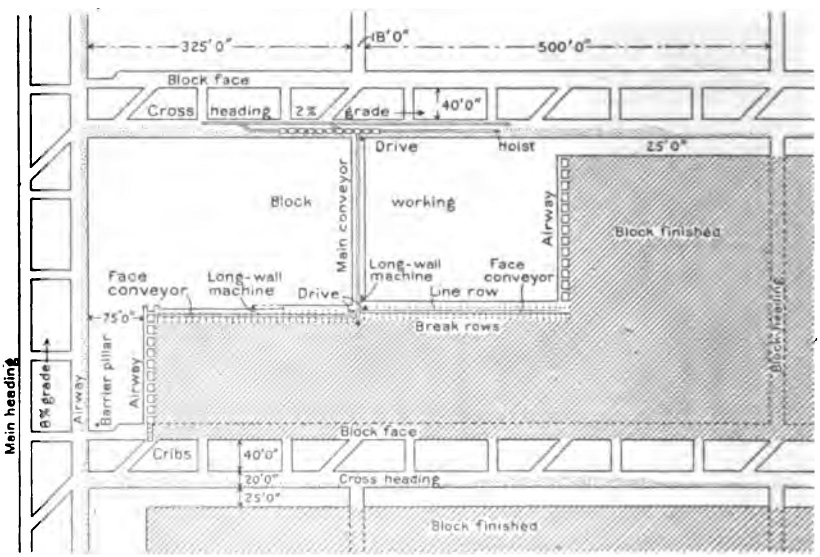

FIGURE 22.—Plan of workings, triple long-wall conveyor system. (From an article by J. I. Thomas in Mines and Minerals, November, 1907, pp. 200-203. Reproduced by permission.)

The first conveyor, which was made entirely of wood, was a cumbersome affair and much time was consumed in moving it laterally along the face after the cut had been loaded out, but after a year's trial the results obtained were so gratifying that metal conveyors were designed and ordered and preparations were made to employ this system on a much larger scale.

The conveyor system is very flexible and numerous methods of working are applicable, as the condition of the territory demands.

In Vintondale, at present, there are two different arrangements—that is, the single conveyor method, which has been mentioned, and the triple-conveyor system, by which two face conveyors dump alternately into a third conveyor, which in turn dumps into the mine cars. Both air and electricity are used as the driving power.

[a] Coal Min. Inst. America, June meeting, 1907. Mine and Quarry, vol. 2, No. 3, February, 1908, pp. 193 et seq. Mines and Minerals, November, 1907, pp. 200-203.

In the No. 3 mine, where the single-conveyor system is being used with compressed air as power, the main heading and air course are driven up the pitch through the center of the property. Cross headings are driven off the main at intervals of 400 feet and run to the outcrop. These headings are 20 feet wide, with an 8-foot roadway carried next to the pillar, which is 40 feet thick. Barrier pillars of 75-foot thickness are maintained on each side of the main entries. Block headings are driven perpendicularly off the cross entries at 265 feet centers. This allows a solid face of 250 feet. These block headings are driven 15 feet wide, but bottom is lifted only 7 feet wide near the rib and of such depth to allow a clearance of 6 feet from the top of rail. The remaining width acts as a shelf for the support of the drive and long-wall machine. As the block headings are driven for a distance of 350 feet into the solid coal, it is found necessary to carry along a good line of bratticing for the purpose of ventilation.

The block nearest the outcrop is first attacked. On this block it is necessary to maintain an areaway at the rear end. This is done by driving along with the block a place 4 feet wide, leaving a pillar 10 feet thick between it and the edge of the block. The coal is extracted to within 25 feet of the upper heading, when the conveyor is removed to the next block, which is worked out in the same manner; and so on until the coal in the whole tier of blocks is recovered. In the meantime the pillar left by the block and the chain pillars are being mined by hand. The time consumed in removing equipment from one block to another is usually about fifteen hours.

The type of conveyor consists of a trough or pan made of sheet steel one-eighth inch thick, 12 inches wide at the bottom, 18 inches wide at the top, and 6 inches high, set on strap-iron standards. The conveyor, which is 250 feet in length, is made up in sections of 6, 12, 15, and 18 foot lengths, connected together by means of one-half inch flat-headed bolts, countersunk. The front is inclined for a distance of 45 feet to allow clearance for mine cars to pass under. The rear end is inclined for 15 feet to compensate for the size of sprocket wheel. A return runway for the chain is afforded below the pans by angle irons.

A cast-iron driving sprocket 18 inches in diameter and 13-inch face is attached to the front end. On the shaft of this sprocket, which is extended 12 inches beyond one of the bearings, is keyed a 12-tooth 16-inch diameter sprocket, which connects with the driving mechanism. The rear-end section consists of a framework made up of two I-beams, 6 feet long and strongly braced, on which rest the take-up boxes for keeping the chain in adjustment and the rear sprocket wheel over which the chain returns.

The conveyor chain is made of either steel or malleable cast iron, held together by bolts, the ends of which may be riveted or fitted with nuts. As it is impracticable to secure a chain that will not break, they are designed so that repair can be made expeditiously.

The power is carried to the different machines by means of a 2-inch pipe, which is run from the main supply along the lower heading to the top of the block heading. A connection is here made with the hoisting engine. The line is carried on props down the block heading to the conveyor, where it is connected by means of a 2½-inch wire-wound rubber hose to a 2-inch pipe that runs the entire length of the block and attached to the conveyor. This pipe has outlets with 2-inch stopcocks at intervals of 50 feet, to which the hose of the mining machines and air drills may be attached. This arrangement necessitates carrying only a short length of hose on these machines instead of one reaching the whole length of the block.

From the end of the conveyor a 1¼-inch pipe is run to the air engine. In this pipe is a valve, which is connected to a rod that reaches to the head end of the conveyor. It is from this point that the conveyor is controlled when running. As the air line needs to be shortened 5 feet nearly every day, several sections of different lengths are kept near at hand, so that this change can be quickly made.

The cars are handled to the conveyor by means of a double cylinder, with an 8 by 10 inch double friction-drum hoisting engine. The drums work loose on the shaft independent of each other and are equipped with a powerful differential brake that will hold any load the engine will hoist; 500 feet of $\frac{5}{8}$-inch rope is reeled on each drum. A small hand drum, on which is reeled 150 feet of $\frac{1}{2}$-inch rope, is used to lower the cars around the curve.

The cars are dropped into the lower heading from the main haulage and pulled, either with mules or a small engine, to the top of the block heading. Here the rope of the small drum is attached to the coupling between the first and second car and the cars pushed around the curve. One of the ropes of the hoist is now attached to the rear end of the trip, which is usually ten cars, and the small rope is freed. The trip is then dropped to the conveyor to be loaded. Another trip is attached to the other rope of the hoist in the same manner. This trip is held on the block entry until the first trip is loaded. This having been accomplished, the loaded trip is dropped to the bottom of the block heading and the rope disengaged. The driver here takes the cars and hauls them to the main haulage. The rope is then pulled to the top of the block heading and attached to the cars, as described. In the meantime the empty trip on the block heading has been dropped to the conveyor and started to be loaded. This change usually occupies two to three minutes. Electric signal wires are run the length of block headings, by which the head man signals the engine boy.

The drive, which is a small double-cylinder engine with reduced gearing, is mounted on a frame and attached to the conveyor. The power is transmitted by means of a steel thimble roller chain to the sprocket on the drive shaft of the conveyor.

The drill used for boring the holes is an ingenious tool; the weight of auger and drill does not exceed 20 pounds. The machine is a small four-cylindered air engine and has a gear on the shank of the machine. The auger is attached to a small chuck that is screwed on to the end of the shank. A hose three-eighths inch in diameter and 50 feet long, attached to the conveyor pipe, furnishes the power for the drill.

The complement of men required to run a block is 13—that is, block boss, machine runner and helper, driller, who also acts as shot firer, engine boy, head man, and six loaders.

The "block boss," or leader of the crew, has direct charge of the block. He must be a man who has some knowledge of mining and the care of machinery, and must possess good executive ability. The balance of the crew, with the possible exception of machine men, are generally non-English-speaking men.

In preparation for the day's work the machine has cut one rail (30 feet) on the previous afternoon. In the morning this coal is shot down and the loaders begin work immediately. It requires from four and one-half to five hours for the machine men to finish the cut. The machine is then overhauled and moved up in position to start the return cut. After finishing their own work the runner and his helper go back on the block and make preparations for the moving of the conveyor. This consists of setting a line of props, called the line row, about 8 feet apart, and a distance from the conveyor equal to the depth of the undercut. As these are placed the old line row, which is now against the conveyor, is withdrawn. The pulling jacks for moving the conveyor are distributed along the block 40 feet apart and placed in position.

The shot firer keeps closely after the machine, and is through shooting shortly after the undercut is finished. He then starts from the far end of the block to drill holes in the new face. It usually takes him about two hours daily to drill the entire width of the block.

Each loader is supplied with a pick and shovel and a piece of sheet iron 9 inches wide and 6 feet long, which he attaches to the conveyor to act as a side board. As each loader cleans up his place he moves forward to the head of the line. This continues until the coal is loaded out, which usually requires about six and one-half hours.

When cleaned up the drive is reversed and the timber, which has arrived on the last trip, is run through on the conveyor to such points on the block where it is required. When this is accomplished the power is shut off by means of a valve located at the top of the block heading. The hose is disconnected from the main feed pipe and the conveyor is moved up to the line row. This lateral move of the conveyor requires very little time, very seldom exceeding five minutes. A break row, consisting of two rows of props set 2 feet apart, is now placed along the lower side of the conveyor. These props are set on a cap piece, placed on a small pile of slack, and wedged at the top. Two break rows are all that is necessary to protect the block. In the meantime a portion of the crew are engaged in pulling out the extra break row. This is the most hazardous work on the block and is given personal attention by the block boss. Axes are used in this operation, and about 75 per cent of the props recovered are practically uninjured.

While the block crew are employed timbering the conveyor man and hoist boy make the necessary pipe connections and go along the conveyor with a pump jack and level it up. They also build a crib at the head end, which is placed so as to prevent the roof from breaking over into the block heading.

When the timber drawers have advanced such a distance from the machine that the noise of the exhaust will not annoy them, the machine begins cutting and is usually able to have one rail, or about 30 feet, cut before the shift is over.

With a 5-foot undercut the block throws 125 tons. Four cuts a week are on an average obtained from each block, which makes a daily average of 100 tons.

Although the results obtained from this system of mining were highly satisfactory, it was found there was still room for improvement, especially with regard to the original cost of the development and the dead work connected with the running of the block. It was with the idea of remedying these features and of improving on other less important conditions that the triple-conveyor system was designed and installed. After being in use for over a year in four of the mines where electricity is the power used the results obtained are even better than were anticipated.

In laying out a mine for this system the main entry and airway are driven up or down the pitch, and cross headings are driven off them at intervals of 400 feet at such an angle as will give a 2 per cent grade; 75-foot barrier pillars are left on each side of the main entries. The cross heading is driven 20 feet wide and gobbed on the lower side. The air course, which afterward is used as the block face, is driven 20 feet wide, but no bottom is lifted; a 40-foot pillar is maintained. Block headings are run perpendicularly off the cross headings at 518-foot centers; they are driven 18 feet wide, with bottom lifted in the center 5 feet wide, and to such a depth as will give a clearance of 5 feet.

When the block is ready for operation a conveyor 350 feet long is placed in the block heading, and along the face of the air course on each side is placed a conveyor 250 feet long, with delivery ends directly over the main conveyor, one being 5 feet in advance of the other. Each conveyor is driven by a 20-horsepower 250-volt series-wound motor incased in a sheet-iron frame mounted on steel shoes, so as to be easily moved.

Airways are maintained on the blocks by driving two places slightly in advance of the block face, 6 and 4 feet wide, respectively, with a 10-foot pillar between. The first place acts as a stable for the machine and is driven by the machine. The airway is pick-mined, and one man manages to keep these other places going on the rear end of both blocks. By this arrangement no cribbing is necessary.

The blocks are worked to within 25 feet of the cross heading, when the conveyors are removed to another block. The remaining pillar is brought back along with the heading stumps.

The power is carried to the top of the block heading by a 2–0 wire. Here are attached two insulated twin cables, one to furnish power to the machines, the other for the drives and hoist.

The cables are carried down the block heading, one on each side of the main conveyor, being attached to it by means of malleable-iron brackets. At the junction of the conveyors connections are made with the drives, also with a cable that is attached to each of the face conveyors.

Stations are established 50 feet apart on the face-conveyor cables, to which connections are made with the short cable attached to the long-wall machines and electric drills. Switches are placed at the head end of the main conveyor, by which the power is controlled.

The method of handling the cars to the conveyor is simple. A side track is laid 300 feet long, of which the block heading is the center. Connection is made with the main track at the lower end, and a crossover switch is placed directly under the conveyor. At the upper end of the siding is placed an electric hoist. A trip of 14 cars is shoved into the empty track, and the rope is attached and the trip pulled up to the conveyor. Signal wires are hung between the conveyor and the hoist, and as each car is loaded the trip is pulled forward. When loaded the trip is dropped on the loaded siding, the rope disengaged and attached to the empties.

The crew operating a double block consists of 17 men—that is, block boss, machine runner and helper, driller, shooter, two conveyor men, hoist boy, five loaders, and four timber men.

Two long-wall machines are used, one for each side, although one machine can keep up the work in case of emergency.

As the machine men finish cutting one block they put the machine in position to start back on the cut and move over to the next block and begin cutting. They are followed by the shooter and loaders. The driller sets the line row and also has time to assist in loading.

When a block is cleaned up the timber men move up the conveyor, set the break rows, pull the timber, and make everything ready for the conveyor to start when the opposite block is loaded out.

The main conveyor, which is made up of 12-foot sections, is disjointed about every third day, and one of the sections taken out and moved to the block heading next to be worked. The surplus length of cable is gathered on a reel located at the head end of the main conveyor.

The working of the face is similar to that of the single block with the exception that the machine men, loaders, etc., continue at their own special work during the whole shift, the dead work being taken care of by the four timber men, thus not hindering the steady flow of coal, which averages 150 tons per day.

For the purpose of keeping the machinery in as good a shape as possible, a skilled mechanic is attached to each mine. He assumes charge in case of an accident and makes necessary repairs, although most of the breakdowns are easily taken care of by the block boss and machine man.

In the starting of a block is where the best results are obtained, as the roof requires little attention until about 100 feet have been extracted. It then begins to weigh heavy on the posts, and it is found necessary to carry three or four double break rows in anticipation of what is called the "big break." This usually occurs when the block is advanced from 100 to 150 feet, although in several instances a 500-foot face has been carried up 200 feet before the overhanging strata broke. After the sand rock is down only two break rows are carried, and the roof keeps breaking behind the last row as the face is extended.

The men are paid day wages, and as they become accustomed to the work and machinery are advanced accordingly. The block boss, as an incentive to secure the best results, is paid a small bonus per ton besides his regular day rate.

The cost averages for the last two years show that block coal is loaded on the mine cars 35 per cent cheaper than the district mining rate, but this cost can be materially reduced when a few improvements now being worked out are brought to a state of perfection. Among these may be mentioned a more simple mechanical rig for spotting the mine cars and a scheme for reducing the amount of timber used.

LITERATURE ON COAL MINING.

For the very latest information and statistical data, together with brief descriptions of the conditions of mines, improvements made therein, and the number and cause of accidents by years, the reader is referred to the annual volume entitled "Report of the Department of Mines, Pennsylvania." Most of the area included in the Johnstown quadrangle was in the sixth bituminous district of the State when this report was written. For information regarding coal-mining methods in general the reader is referred to the "Coal and metal miners' pocket book," ninth edition, 1904, pages 280 et seq.

CLAY AND SHALE.

MODE OF TREATMENT.

The clay materials of the Johnstown quadrangle are flint clays, plastic clays (including some fire clays), and shales.

On pages 14 to 28 of this bulletin a detailed description is given of the rocks in which the workable or potentially workable shale and clay beds are found, and to these preliminary descriptions the reader is referred for an explanation of the names which are applied to the beds containing the clays and which are employed in the following discussions. The treatment of the clays, like that of the coal, will be twofold, consisting of (1) a preliminary description of their general character and geologic position, followed (2) by a detailed description by districts, intended for the use of those who are more particularly interested in the subject. The detailed descriptions will be accompanied by analyses and sections. The distribution of the clay beds which are regarded as of economic importance is shown on Plate I by means of purple lines.

GENERAL DESCRIPTION.

FLINT CLAYS.

Flint clays occur at three or more horizons in the Johnstown area. The highest is in the Conemaugh formation and ranges in position from 50 to nearly 100 feet above the Upper Freeport coal. It usually occurs very close to the Mahoning coal in the hills immediately about Johnstown, and its distance above the Upper Freeport coal is therefore nearer 50 to 75 feet than 100 feet. A clay in a similar position with respect to the top of the Allegheny formation was also observed in the hills north of South Fork. It appeared to be of the ordinary plastic variety. In the Blacklick Creek district, near Wehrum, a flint clay has been observed at many places in a similar position with reference to the Mahoning sandstone member. This flint clay, which in many places attains a thickness of 7 feet, is probably to be correlated with the flint clay occurring near Johnstown.

In the Allegheny formation a flint clay was observed near the northwest edge of the quadrangle, in the valley of Mardis Run. It occurs 25 feet below the Upper Freeport coal and probably corresponds with the Bolivar flint clay of the area to the west.

The most important flint clay in the entire quadrangle is that occurring at the Mercer horizon in the hills about South Fork, where it is associated with plastic clay. In the mine of J. H. Wickes it is 4½ feet thick. The flinty character is persistent between South Fork and Mineral Point, but elsewhere throughout the quadrangle the Mercer member is usually characterized by a band of shale and plastic clay.

PLASTIC CLAYS.

Plastic clays have been observed at many horizons in the Johnstown quadrangle. At only a few places, however, are their position with reference to transportation facilities and their thickness such as to make them of great economic importance. A few plastic-clay beds have been observed in the Conemaugh formation. Many of the coals in the Allegheny formation are underlain by plastic clays. The clay below the Upper Freeport is of workable thickness at some places. Below the "cement rock" associated with the Upper Kittanning (Cement) coal a deposit of clay was noted at some places around Johnstown. The most important plastic clay in the Allegheny formation is that below the Lower Kittanning (Miller or B) coal bed, and it is extensively mined around Johnstown and South Fork in connection with that coal. It is mixed with the flint clay from South Fork and Dean station to make all grades of fire brick and refractory material in general. This clay varies in thickness from less than 3 feet to 12 feet, of which from 2½ to 5 feet is worked in the most important clay mines near Johnstown. At Seward 12 feet of clay is reported below the Lower Kittanning coal, but of this thickness only 6 feet is mined and used in the manufacture of buff or light-colored brick.

In the northern part of the quadrangle, along Blacklick Creek and at Conemaugh Furnace, the clay below the Lower Kittanning coal is of workable thickness, and there is no reason why its quality should not compare with that of the plastic clay near Johnstown and South Fork. So far as known, however, it has never been mined in connection with the coal in either of these districts.

The lowest plastic clay in the region occurs at the Mercer horizon. This clay is associated with and occurs immediately above the flint clay at the same horizon near South Fork. Plastic clay of Mercer age is also found on Stony Creek in the hills north of the mouth of Paint Creek and farther to the south. It is also present in the hills north of Sheridan and is worked at a quarry in this locality. The corresponding clays have been prospected but are not worked at present on the west slope of Laurel Ridge, a few miles southeast of Conemaugh Furnace.

SHALES.

In the Johnstown quadrangle valuable shale beds are scattered through the Conemaugh and Allegheny formations, and in the Pottsville formation the Mercer member is nearly everywhere characterized by the presence of a shale bed of varying thickness. Near Johnstown valuable shale beds occur in the lower 300 feet of the Conemaugh formation and are worked near the city. The higher beds of the Conemaugh are exposed in the railroad cuts west of Wilmore, and the numerous shale beds there included (see section, p. 16) insure the presence of much good brickmaking material admirably situated with respect to transportation. At the Bruce H. Campbell quarry, north of Sheridan, a clay that is associated with rounded bowlders and is presumably of Pleistocene age is worked (Pl. V, *B*). Residual clays are so widely distributed in this quadrangle as hardly to merit detailed mention.

DESCRIPTION BY DISTRICTS

JOHNSTOWN DISTRICT.

FLINT CLAYS.

Flint clay occurs persistently at but one horizon in the Johnstown district. This horizon is at or just above the Mahoning sandstone member and in the hills surrounding the city it is 50 to 70 feet above the Upper Freeport (Coke Yard) coal. Though fairly well distributed in favorable locations for easy exploitation, this clay is, so far as known, worked only by the Johnstown Pressed Brick Company at its plant on a hill east of the city. A section of the rocks in the hill will show the position of this clay and its relation to the underlying coal, which is at the top of the Allegheny formation.

Section of lower part of Conemaugh formation in hill east of Johnstown.

	Feet.
Concealed, and sandstone from top of hill	91
Shales	10
Shales, black	5
Shales, brick-red	40
Concealed, but probably shales	25
Shales, dull olive, weathering reddish [a]	25
Shales, olive to red	5
Shales, dark olive green, slightly gritty, with iron oxide and manganese oxide on the bedding planes [a]	13–15
Sandstone, laminated	15
Shales	30

[a] Beds worked for brick material.

	Ft.	in.
Concealed, but with a sandstone in its upper part	42	
Flint clay.[a]		
Shales	8	
Shales, ferruginous	10	
Shales, green, concretionary	10	
Shales, irregularly bedded	5	
Shales, sandy	8	
Sandstone, massive (Mahoning)	25	
Concealed	12	
Coal, 3 feet 6 inches; Bone, 5 inches } Upper Freeport (Coke Yard) coal	3	11

Fragments of flint clay have been seen in the following localities near Johnstown: On the road ascending Shingle Run, in Dale Borough, east of Johnstown, more than 2 feet of flint clay associated with shale was measured 60 feet above the Mahoning sandstone member. An old prospect hole on this flint clay was seen on the road leading to Grandview Cemetery, in which the clay was about 65 feet above the Upper Freeport (Coke Yard) coal; it was of a light-straw color and appeared to be of good quality. On the Ferndale-Johnstown road, a short distance north of the Eighth Ward mine of the Citizens Coal Company, an abundance of flinty clay débris occurs above the road near the top of the massive Mahoning sandstone. In the hill above the Baltimore and Ohio Railroad tunnel east of Island Park, on the new county road, some flint clay was observed about 40 feet above the Upper Freeport coal and near the top of the Mahoning sandstone. Northwest of Johnstown, in the hills bordering Laurel Run and its branches on the east, a short distance east of the old coke yard from which the Upper Freeport gets its local name, this flint clay is exposed, indicating a probable continuity of the bed as far west as the valley of Laurel Run. Here again the flint clay is about 50 feet above the Upper Freeport coal. Northwest of Johnstown, on the road ascending Pleasant Hill from the valley of Conemaugh River, a flint clay occurs about 110 feet above the Upper Freeport coal and 10 feet below a smaller bed of coal. This smaller bed of coal may possibly be higher stratigraphically than the seam 70 feet above the Upper Freeport at the Baltimore and Ohio Railroad tunnel near Island Park; if so, the flint clay of Pleasant Hill is higher than that previously described, and there are two flint-clay horizons in the 100 feet at the base of the Conemaugh formation. At the southern edge of the quadrangle, in Somerset County, in the hills bordering Stony Creek, this same flint clay has been observed.

Should the clay after careful prospecting prove to be present in sufficient quantity and of such quality as to justify its exploitation at the above-named localities, it could be marketed, as most of the

[a] Beds worked for brick material.

occurrences which have been noted are conveniently situated with respect to transportation. Deposits of this clay too far removed from market and transportation to have commercial value have also been observed on the headwaters of Mill Creek and Dalton Run.

It should be added that the occurrences noted above are largely roadside outcrops at which it is impossible to determine the exact thickness and nature of the clays. Only careful prospecting can determine these points, but the fact that one of the flint clays is being exploited at one locality is significant.

PLASTIC CLAY.

The flint clay above the Mahoning sandstone assumes a plastic phase at places in the Johnstown district. Most of the valuable plastic clay in this region, however, occurs in the Allegheny formation ("Lower Productive Coal Measures"). At a few places a clay bed of workable thickness occurs below the Upper Freeport coal, in connection with which it might be mined. At the Cyrus Shepard mine, leased by L. J. Mitchell, east of Franklin and near the mouth of Clapboard Run, 2 feet 4½ inches of clay were measured by Mr. Martin, but the clay is known not to be persistent, as but a short distance away the section obtained shows an entirely different aspect.

A clay bed underlies the Johnstown limestone member—that is, the limestone occurring near or just below the base of the Upper Kittanning (Cement) coal. This clay has been worked, but it is not now exploited. It is referred to in the report on this district by F. Platt and W. G. Platt[a] as having been developed by Mr. Haws, of Johnstown. The clay was analyzed by T. T. Morrell,[a] with the following results:

Analysis of clay occurring below the Johnstown limestone member.

Silica (SiO_2)	71.98
Alumina (Al_2O_3)	26.29
Ferric oxide (Fe_2O_3)	2.21
Magnesia (MgO)	.44
Manganese dioxide (MnO_2)	.32
	101.24

The most valuable clay in the Allegheny formation is that underlying the Lower Kittanning (Miller) coal. Many of the mines working this coal around Johnstown produce also considerable amounts of the clay. The clay bed in this district ranges from less than 3 to about 6 feet in thickness, but locally it may be even thicker than this. It usually underlies the lower bench of the Lower Kittanning coal, from which it is separated by a few inches of shale; or, in the absence

[a] Second Geol. Survey Pennsylvania, Rept. H2, 1875, p. 148.

of the lower bench, it occurs below the main coal itself, separated from it by about 3 to 4 inches of bone or shale. It is a light-drab clay, not very hard, of irregular fracture, greasy to the touch, and slakes on exposure to the weather. Its composition is indicated by the following analyses:

Analyses of clay underlying the Miller seam.

	1.	2.	3.	4.
Silica (SiO_2)	65.90	66.40	53.10	68.82
Alumina (Al_2O_3)	20.30	19.80	27.80	20.85
Ferric oxide (Fe_2O_3)	[a] 1.60	[a] 1.68	[a] 3.08	2.79
Magnesia (MgO)	.66	.61	.60	.23
Lime (CaO)	.09	.10	.22	.82
Soda (Na_2O)	.34	.30	.48	....
Potash (K_2O)	2.98	3.24	3.58	....
Titanium oxide (TiO_2)	1.20	1.00	1.20	MnO_2 .66
Loss on ignition	6.50	6.40	10.20	5.83
	99.57	99.53	100.26	100.00

[a] Total iron calculated as Fe_2O_3.

1. Citizens' Coal Company's Green Hill mine, Johnstown; E. C. Sullivan, analyst.
2. A. J. Haws & Sons (Limited) mine, near the stone bridge, Johnstown; E. C. Sullivan, analyst.
3. Seward Coal Company's mine, Seward, Westmoreland County, Pa.; E. C. Sullivan, analyst.
4. Clay underlying the Lower Kittanning (Miller) seam at Johnstown; T. T. Morrell, analyst. Second Geol. Survey Pennsylvania, Rept. H2, p. 148.

This clay is worked about Johnstown by W. J. Williams at Kernville. Below the coal at the Kernville mine there is a shale layer of varying thickness, about 2 to 6 inches in places, below which is from 3 to 5 feet of plastic clay. This clay is mined and used at one of the local brickyards. At the Green Hill mine of the Citizens' Coal Company the average thickness of the underlying clay is 5 feet. This also is shipped to a local brick plant. This clay is mined by A. J. Haws & Sons (Limited), both at their shaft near the famous stone bridge in Johnstown and to the west at Coopersdale. In the shaft workings an average of nearly 3 feet is worked. At Coopersdale it averages 3½ feet in thickness but in places runs as thick as 5 feet. It was observed in the mine that when the clay attained its maximum thickness the coal appeared in a single bench, with its lower 4 or 5 inches bony. At both the Haws mines the Lower Kittanning coal is mined with the clay, and is used as the fuel to burn the brick at the brick plants situated at the mine mouths. The clay is also mined by Robertson & Griffith on St. Clair Run in connection with the overlying coal.

Nearly all the product of the Johnstown clay mines is used at local brick plants, where it is mixed with flint clay from the Mercer horizon, shipped chiefly from South Fork and Dean station. When thus mixed with the flint clay it forms a suitable bond in a product that is used in the manufacture of high-grade refractory products and bricks for blast-furnace and open-hearth work, and in making sleeves, nozzles, tuyeres, and other articles exposed to high temperatures. In the most refractory products nothing but flint clay is used.

The lowest plastic clay in the Johnstown quadrangle is associated with the Mercer coal and is not exposed immediately about the city. In the hills lying east of Stony Creek, south of Kring, on the Baltimore and Ohio Railroad, this horizon has been prospected and some clay and shale have been found, but they have never been worked. At one exposure of the Mercer south of the quadrangle, on the west flank of the Ebensburg anticlinal axis, more than 11 feet of clays and shales were measured in one exposure. Flint clay was not observed in connection with the Mercer at any of the old prospect pits.

North of Sheridan, at the quarry of Bruce H. Campbell, the following section was measured, showing 6 feet and possibly more of clay below the Mercer coal:

Section of Mercer shale member at Bruce H. Campbell quarry, north of Sheridan.

	Ft.	in.
Sandstone in massive bowlders.		
Clay, red, with rounded bowlders (Pleistocene?)	5–10	
Shales	20	
Coal and bone	1	3
Clay	6	
Shales	6	

That the underlying clay and shales are much thicker than is indicated by the above section has been proved by sinking three test holes. Both red and buff building bricks are made from the clays and shale quarried here.

SHALES.

It has been remarked that the most important shale horizons about Johnstown are confined to the lower 300 feet of the Conemaugh formation. The section given on pages 115–116 shows the character of the lower 400 feet of beds in this group of rocks in a hill east of the city. From about 50 feet above the top of the Upper Freeport (Coke Yard) coal to the top of the hill numerous promising beds of shale are exposed. Most of the shale group lying between 165 and 210 feet above the Upper Freeport coal is being worked by the Johnstown Pressed Brick Company into a good building brick of both the buff and red varieties. The fuel used in burning the brick is obtained from the Upper Freeport coal, which the company works in the same hill. The shales are ground through a 12-mesh sieve, or to a size to make them "ball." The material is then hoisted by a bucket-belt conveyor to the sieve, thence sent through a hopper to the pans, after which it is pressed into brick, the dry-press process being used.

The composition of the shales employed is indicated below. The shales were first air dried and then subjected to the usual fusion, with subsequent analyses.

Ultimate and rational analyses of shales from hill east of Johnstown.

	1.	2.
Silica (SiO_2)	51.32	64.29
Alumina (Al_2O_3)	24.39	17.95
Ferric oxide (Fe_2O_3)	6.94	5.74
Manganese oxide (MnO)	.14	Trace.
Lime (CaO)	.70	.46
Magnesia (MgO)	1.73	1.30
Sulphuric anhydride (SO_3)	Trace.	Trace.
Ferrous oxide (FeO)	1.43	1.64
Alkalies (Na_2O)	.23	.35
Alkalies (K_2O)	1.09	1.80
Water at 100° C.	.92	.95
Ignition loss	11.32	5.44
	100.21	99.92
Free silica	10.09	28.54
Clay substance	81.51	57.85
Feldspathic substance	8.40	13.61
	100.00	100.00

1. Sample collected from upper shale bed: see section (p. 115). Analysis made at the structural-materials laboratory of the United States Geological Survey at St. Louis. A. J. Phillips, analyst.
2. Sample collected from lower shale bed; see section (p. 115). Analysis made at the structural-materials laboratory of the United States Geological Survey at St. Louis. P. H. Bates, analyst.

In Prospect Hill, north of Johnstown, the Cambria Steel Company has quarried shale lying about 80 to 100 feet above the Upper Freeport coal and utilized it in connection with the overlying surface clay in the manufacture of red building brick of good quality. The brick plant of the company is located at Cambria.

The geologic structure immediately near Johnstown is such that the beds lie fairly flat and the lower few hundred feet of the Conemaugh formation is exposed. Sections obtained in the hills around the city and along the Pennsylvania Railroad to the west indicate that the lower part of this formation is of prevailingly shaly character, comparable with that seen in the hill to the east. It is therefore probable that a great deal of brickmaking material exists in these hills which has never been tested. Though all this shale may not be of the grade of that worked by the Johnstown Pressed Brick Company, some of it probably is, and much of it may be suitable for paving brick, sewer pipe, fireproofing of various sorts, and other rough material. All the shale in the hills about the city and to the west is fairly accessible to transportation, and cheap fuel is assured by the presence of valuable coal beds 300 feet or more below.

The lowest promising shale horizon in this district is associated with the Mercer coal. The prospect pits on the Baltimore and Ohio Railroad south of Kring show the presence of dark shales at this horizon. At points north of Sheridan the Mercer shale is thick and is worked in connection with the overlying Pleistocene clays at the quarry of Bruce H. Campbell. (See Pl. V, *B*, p. 28.) The section on page 119 shows 20 feet of shales overlying the coal, and the thickness of brickmaking material at the base of the section is known from test holes put down by the company to be much greater. The shales in the 20-foot bed given near the top of the section are dark brown and drab in color, somewhat sandy, and concretionary. This shale is mixed with the overlying clay, and the mixture is used in making a buff or red building brick, the color depending on the proportions of shale and clay used. The beds worked at this quarry rise abruptly toward the west at a rate that soon carries the Mercer horizon with its shales over the tops of the hills.

Mr. Martin collected a sample of the shale from this quarry, taking it from the entire width of the exposure and then mixing it with the overlying clay in the proportion of 2 parts of shale to 1 of clay. The sample was analyzed by P. H. Bates, of the structural-materials laboratory of the Survey at St. Louis, with the following results:

Ultimate and rational analyses of shale and clay from Mercer shale member, B. H. Campbell quarry, north of Sheridan.

Silica (SiO_2)	62.86
Alumina (Al_2O_3)	18.85
Ferric oxide (Fe_2O_3)	5.19
Manganese oxide (MnO)	.37
Lime (CaO)	1.42
Magnesia (MgO)	.98
Sulphuric anhydride (SO_3)	.11
Alkalies {Na_2O	.06
Alkalies {K_2O	2.59
Water at 100° C.	2.27
Ignition loss	5.45
	100.15
Free silica	27.70
Clay substance	56.41
Feldspathic substance	15.89
	100.00

SOUTH FORK DISTRICT.

FLINT CLAY.

A band of clay that occurs in the Pottsville formation in the South Fork district has been worked at points south of the Pennsylvania Railroad from South Fork westward beyond Mineral Point and also at a few places north of the railroad. In this district this clay is characterized by a persistent flinty streak. This clay is present in the hills along Conemaugh River in an area extending west to about 1 mile east of Conemaugh station. The outcrop is continuous except where the local dips and change in direction of the river carry it below drainage. The flinty clay may not be present at all points between Mineral Point and Conemaugh. For example, the clay observed at this horizon in the tunnel of the old Portage Railroad is not particularly flinty in character. From Mineral Point to South Fork, however, the flinty character is persistent.

This flint clay is now worked by the Garfield Fire Clay Company near the viaduct and by J. H. Wickes and the South Fork Fire Brick

Company west of South Fork. The following section was measured at Mr. Wickes's mine:

Section of fire clay at J. H. Wickes's mine, South Fork.

	Ft.	In.
Heavy sandstone roof.		
Clay, plastic	3	6
Coal		½–2
Clay, flint	4	6
Sandstone.		

This clay was also worked by the Page-Reigard Mining Company near Mineral Point and at South Fork, but in July, 1904, the mine at South Fork was shut down. It is reported that the plastic clay is persistent but that the thickness of the flint clay is variable, dwindling to 14 inches in a northeast-southwest zone. A specimen of the clay was collected in October, 1906, and analyzed by A. J. Phillips at the structural-materials laboratory of the United States Geological Survey at St. Louis. This analysis (No. 1 in the table below) may be compared with an analysis of what is believed to be clay from the Mercer, taken from the central band of the bed worked years ago near the viaduct. This latter clay was not definitely fixed in its stratigraphic relations by the Platts.[a] It was regarded by them as clearly underlying all the workable coals and as being connected with the "Conglomerate Rock," as the Pottsville was sometimes called, and as being the equivalent of the fire clay of Sandy Ridge, which is known to be in the Mercer member. The third analysis in the table represents clay from the middle layer in the Sandy Ridge bed.

Ultimate and rational analyses of Mercer clays.

	1.	2.	3.
Silica (SiO_2)	44.30	45.42	44.950
Alumina (Al_2O_3)	38.31	36.80	37.750
Ferric oxide (Fe_2O_3)	1.40	[b] 3.33	[c] 2.700
Manganese oxide (MnO)	.10	[d] .48	....
Lime (CaO)	.82	.87	.302
Magnesia (MgO)	.59	.45	.216
Sulphuric anhydride (SO_3)	Trace.	....	....
Ferrous oxide	.71	....	....
Alkalies: Na_2O	.22	....	.985
Alkalies: K_2O	.17		
Water at 100° C	.75	....	....
Ignition loss	12.77	[e] 12.65	[e] 13.050
	100.14	100.00	99.953
Free alumina	3.88	....	....
Clay substance	93.26	....	....
Feldspathic substance	2.86	....	....
	100.00	....	....

[a] Second Geol. Survey Pennsylvania, Rept. H2, 1875, p. 146.
[b] All iron reported as peroxide of iron.
[c] Reported "oxide of iron."
[d] Calculated as MnO_2.
[e] Reported as water and organic matter.

1. Flint clay from Mercer horizon, A. J. Wickes's mine, South Fork; A. J. Phillips, analyst.
Flint clay from Mercer horizon, near the viaduct; T. T. Morrell, analyst, Second Geol. Survey Pennsylvania, Rept H_2, 1875, p. 147.
3. Fire clay of Sandy Ridge; A. S. McCreath, analyst, Second Geol. Survey Pennsylvania, Rept. H, 1874, p. 119.

There is a striking similarity among these analyses.

At South Fork the clay is smooth, hard, compact, light to dark gray in color, breaks with a conchoidal fracture, and burns to a straw-yellow color. The analysis indicates a high-grade material, with perhaps a little too much iron.

The clay mined at South Fork is in part shipped to Johnstown and in part mixed with plastic clay from the Lower Kittanning seam and used at the local brick plant. Some of the products of this flint clay have been tested for refractoriness at the plant of the Cambria Steel Company at Johnstown and have proved highly satisfactory.

PLASTIC CLAY.

About South Fork a plastic clay of doubtful value has been observed at a few places near the top of the Mahoning sandstone; its position corresponds with that of the band of flint clay in the Johnstown district. The clay below the Upper Freeport (Lemon) coal bed is fairly thick in this region, but it is not worked at present. At O. M. Stineman's mine No. 3 this coal is underlain by 2 feet 3 inches of clay, which may be worked at some future time in connection with the coal. This clay is not comparable in thickness with that which directly underlies the Lower Kittanning (Miller) coal seam, and which about South Fork, as near Johnstown, is the most important plastic clay in the Allegheny formation. The plastic clay associated with the Lower Kittanning coal seam is usually workable, at some places having a thickness of 6 to 8 feet and averaging about 3 to 4 feet of workable clay of good grade. A brief note on the character of this clay will be found in the description of its occurrence in the Johnstown district (p. 117), where analyses also are given. There is every reason to suppose that in this district it is of the same quality as about Johnstown. Most of the South Fork clay is mined in connection with the coal and is used almost entirely at the local brick plant.

SHALE.

So far as known the shales in the South Fork district have not been utilized. In the two large cuts west of the town of Wilmore, on the main line of the Pennsylvania Railroad, shale beds are exposed that vary in position from 400 to 675 feet above the Upper Freeport coal. In the surrounding hills many promising shales are found conveniently situated with respect to transportation. Their appearance indicates that they may be adapted to the manufacture of paving brick and other materials that require only an inferior grade of clay or shale; to determine their fitness for any purpose, however, practical tests must be made. In a recent cut opposite Ehrenfeld, along the new county road, a bed of shale 50 to 60 feet thick, lying 60 feet above the Upper Freeport coal, also appears to be promising.

BLACKLICK CREEK DISTRICT.

The South Branch of Blacklick Creek flows along the northern edge of the Johnstown quadrangle. It is joined by the north branch a short distance west of Vintondale, and the main stream flows westward beyond the limits of the area. Deposits of flint and plastic clay are found in the adjacent hills along the creek, and although many of these are conveniently situated with respect to lines of transportation the demand has not yet been sufficient to justify their exploitation.

FLINT CLAY.

The flint clay in the Blacklick Creek district occurs at two horizons. The higher is found in the lower part of the Conemaugh formation, above what is thought to be the equivalent of the Mahoning sandstone member and a few feet below a small coal bed, possibly the Mahoning coal. This flint clay has been observed in many places north, west, and south of Wehrum, but the rise of the beds toward the east causes a gradual increase in its distance from the valley and from transportation facilities and finally its complete absence from the hills. West of Wehrum, however, both north and south of Blacklick Creek, it occurs at many points, having in places the unusual thickness of 7 to 8 feet. It is a typical flint clay in appearance, though its content of iron oxide is apparently very high. A sample collected from a roadside exposure west of Dilltown gave the following analysis:

Partial analysis of flint clay from a natural exposure west of Dilltown.

[E. C. Sullivan, analyst.]

Silica (SiO_2)	50.3
Alumina (Al_2O_3)	21.3
Ferric oxide (Fe_2O_3)[a]	10.4
Magnesia (MgO)	.61
Lime (CaO)	.39
Soda (Na_2O)	.18
Potash (K_2O)	1.14
Titanium oxide (TiO_2)	.90
Loss on ignition	12.00
	97.22

The percentage of fluxing materials, principally iron oxide, indicated in this analysis, is so high as to prohibit its practical use. A lower flint clay, lying a few feet below what may prove to be the Upper Freeport coal, was seen at a few places in the valley of Mardis Run, near the northwestern edge of the quadrangle. This clay may correspond to the Bolivar clay of the region to the southwest. Two feet of clay was seen at one point on the outcrop and the bed may possibly be thicker. This clay is rather remote from transportation.

[a] Total iron calculated as Fe_2O_3.

PLASTIC CLAY.

The coal that is being extensively worked in the valley of Blacklick Creek is regarded as the equivalent of the Lower Kittanning (Miller or B) seam of the Johnstown and South Fork districts. In the Blacklick Creek district, as well as along Conemaugh River, this coal is underlain by a promising clay bed. This clay is not exploited at present, and no certain measurement of its thickness was obtained. At many of the mines 2 feet or more of promising clay was seen, comparable, in appearance at least, with that in the Johnstown district.

MISCELLANEOUS LOCALITIES.

Along the western flank of Laurel Ridge, near the line of the Pennsylvania Railroad, the Lower Kittanning (Miller) coal has been opened at a few places and the clay underlying it found to be of workable thickness. At the coal mine of the Johnstown Coal Company more than 2 feet of clay was seen; and near Seward, beyond the western limits of the quadrangle, 12 feet of clay occurs in the same position, 6 feet of which is worked by the Seward Brick Company.[a]

About 2 miles southeast of Conemaugh Furnace, on the main line of the Pennsylvania Railroad and south of it, the Conemaugh Stone Company has done considerable quarrying in the Pottsville and has exposed the Mercer shale member. The following section was measured but does not show the complete thickness of the clay:

Section showing Mercer shale member and accompanying clays at quarry of Conemaugh Stone Company.

	Ft.	in.
Shale, dark, with 2 inches of bone near base	3	
Fire clay	1	
Clay, sandy	1	
Clay, good, drab	1	
Coal or smut		½
Clay, drab	5+	

PRODUCTION.

The firms named below are engaged in the brick and clay industry in this area. In addition coal companies mining the Lower Kittanning coal about Johnstown and South Fork may produce small quantities of the underlying clay for use in the local brick plants.

Clay miners:

- Page-Reigard Mining Company, flint clay, Mineral Point.
- W. J. Williams, plastic clay, Kernville.
- Citizens' Coal Company, plastic clay, Green Hill mine, Johnstown.
- Robertson & Griffith, plastic clay, St. Clair Run, Morrellville.

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[a] For an analysis of the clay underlying the coal mined at Seward, see p. 118.

Manufacturers of fire brick:
- A. J. Haws & Sons (Limited), Johnstown and Coopersdale.
- Hiram Swank Sons, Johnstown.
- South Fork Fire Brick Company, South Fork.

Manufacturers of building brick:
- Cambria Steel Company, Johnstown.
- Bruce H. Campbell Brick Company, Sheridan.
- Johnstown Pressed Brick Company, Johnstown.

BRICK INDUSTRY.

The brick industry in the vicinity of Johnstown has grown to considerable magnitude. Some of the flint clay used in the manufacture of the fire brick and other more refractory products is shipped from other parts of the State, but except for this most of the raw material used is of local occurrence.

LIMESTONE AND CEMENT MATERIALS.

EXTENT.

In the Conemaugh formation of western Pennsylvania numerous limestone members have been found and traced with certainty over broad areas. These have been proved to be so constant in their position in the geologic column that they have been named and have served as guides in unraveling the stratigraphy. Some of these are the Pittsburg, Clarksburg, Elk Lick, Ames or "Crinoidal," and Upper and Lower Cambridge limestone members of the Allegheny Valley, and the Johnstown iron-ore bed, which is in places nothing more than a ferruginous limestone at an inconsiderable distance from the outcrop. Some of these limestones undoubtedly occur in the Johnstown quadrangle. Actual correlation has not been made, however, partly because the limestones in the quadrangle are regarded as lenticular and partly because they are so numerous that they can not be correlated certainly with the persistent and characteristic limestones of the Allegheny Valley.

The limestones of the Conemaugh are of no importance whatever commercially and have never been used except for fertilizing purposes on a very small scale. The limestones in the Allegheny are of greater importance than those in the Conemaugh. They are three in number—the Upper Freeport limestone member, the Lower Freeport limestone member, and the Johnstown limestone member.

UPPER FREEPORT LIMESTONE MEMBER.

The Upper Freeport limestone member appears in the section only near South Fork and Ehrenfeld. A short distance east of Ehrenfeld it is exposed in some recent excavations along the main line of the Pennsylvania Railroad. It is a gray limestone from 1½ to 3 feet in thickness and at Ehrenfeld it is very irregularly bedded. It lies a short distance below the Upper Freeport coal, being separated from it by about 2 feet of clay containing limestone nodules in its lower foot. So far as known, this particular limestone has never been used in this area.

LOWER FREEPORT LIMESTONE MEMBER.

The Lower Freeport limestone member occurs either directly below or within a foot of the base of the Lower Freeport coal, the slight interval as a rule being occupied by black shale. It ranges from 1½ to nearly 4 feet in thickness. The best exposures in the quadrangle occur along Stony Creek (Pl. IV, *A*, p. 24) and the Baltimore and Ohio Railroad between Moxhom and the mine of the Valley Coal and Stone Company. This limestone has never been used in any way.

JOHNSTOWN LIMESTONE MEMBER.

The limestone occurring below the Upper Kittanning or Cement coal is known locally as the Johnstown cement bed. It is best developed along Stony Creek and may be seen to advantage on the Baltimore and Ohio Railroad north of Kring, where it is 6 feet thick and is separated from the coal by 8 to 12 inches of shale. Along the spur track leading from the north end of the Baltimore and Ohio tunnel to the mine of the Valley Coal and Stone Company it is also conspicuous but slightly thinner. (See Pl. VII, *A*, p. 48.) The sections measured by hand level (see pp. 44 and 47) indicate the relations of this limestone and show its thickness where measured in this part of the quadrangle. The bed is nearly 8½ feet thick near Conemaugh depot and nearly 5 feet in the section along the Pennsylvania Railroad to the west, approaching Johnstown depot. To the east, on Conemaugh River, it is exposed just at the northwest apex of the first big meander. It must be thick in all the intermediate territory. Its outcrop along Stony Creek near the Rolling Mill mine of the Cambria Steel Company is also conspicuous. Northwest of Johnstown, near the old Cambria furnace and at the east base of Laurel Hill, it outcrops and shows just above the waters of Laurel Run. Here it is a bluish limestone with a few streaks of calcite. It is present but not very thick near South Fork, and is also reported near Scalp Level, just across the Somerset County border.

In the reports of the Second Geological Survey of Pennsylvania[a] this bed is called the "Ferriferous limestone," but its identity with the limestone of the same name of the Allegheny Valley was left open for more complete and harmonious evidence than was available when the report on Cambria and Somerset counties was written.

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[a] Rept. H2, 1877, pp. 150 et seq.

The limestone at this horizon was worked at one time. In the report of the Second Geological Survey, Platt mentions the Haws Cement Works as utilizing this rock occurring on Stony Creek not far from the Rolling Mill mine. He describes it as being bluish gray in color, hard, and brittle, showing small crystals of iron pyrites, and containing considerable clay. The deposit worked was dolomitic in character. The sample collected near Kring for analysis is also dolomitic in character. (See analysis 1.) Such high magnesian limestones have been used in the manufacture of natural cements near Utica, La Salle County, Ill., in the Louisville district of Indiana and Kentucky, and in the Rosendale district, Ulster County, N. Y. The magnesia, in natural cements at least, may be regarded as equivalent to lime so far as the hydraulic properties of the product are concerned. The presence of magnesium carbonate in a natural cement rock is merely incidental, while the silica, alumina, and iron oxide are essential. For comparison average analyses of limestones from the different districts mentioned above are given below, together with that of the limestone near Johnstown:

Analyses of limestones suitable for making cement.

	1.	2.	3.	4.
Silica (SiO_2)	14.44	20.92	13.34	18.04
Alumina (Al_2O_3)	7.82		3.46	6.18
Ferric oxide (Fe_2O_3)	1.54	2.35	1.90	2.63
Manganese oxide (MnO)	.20	....	....	....
Lime (CaO)	25.05	26.32	31.49	25.23
Magnesia (MgO)	13.29	12.10	11.19	12.47
Sulphuric anhydride (SO_3)	.15	[a] 1.81	....	[b] .78
Alkalies Na_2O	.28	[c] .18	....	n. d.
Alkalies K_2O	.86			n. d.
Water at 100° C	.28	36.73	[e] 37.07	[d] 1.20
Ignition loss (includes CO_2)	36.48			[e] 33.31

[a] Average of two analyses.
[b] Average of five analyses.
[c] Average of two analyses, one of which is too low.
[d] Result of one analysis.
[e] Includes only CO_2.

1. Sample collected on Baltimore and Ohio Railroad north of Kring. Analysis made at structural-materials testing laboratory, United States Geological Survey, St. Louis, Mo. A. J. Phillips, analyst.
2. Average of five analyses of natural cement rocks, Utica, Ill. Eckel, E. C., Bull. U. S. Geol. Survey No. 243, 1905, p. 340.
3. Average of six analyses of natural cement rocks, Louisville district, Indiana-Kentucky. Eckel, E. C., Bull. U. S. Geol. Survey No. 243, 1905, p. 341.
4. Average of six analyses of natural cement rocks, Rosendale district, New York. Eckel, E. C., Bull. U. S. Geol. Survey No. 243, 1905, p. 346.

The close agreement among the foregoing analyses strongly suggests that the Johnstown limestone member may be of value in the future for local use only in making natural cement. Its cementation index is 1.14, which places it in class A, according to the scheme of E. C. Eckel.[a] According to Eckel, products having an index between 1.00 and 1.15, when burned at sufficiently high temperature, are slow setting and high in tensile strength. They include the "natural Portlands" and allied products. If not burned high enough, cements

[a] Cements, limes, and plasters, 1905, pp. 198–199.

of such low index will contain free lime and magnesia. This particular product near Johnstown stands near class B (in which the cementation indexes run from 1.15 to 1.60). In this class are included most American natural cements and nearly all European Roman cements. As a rule it is not necessary to burn these products at so high a temperature as those in class A.

The composition of the Johnstown limestone member differs from place to place, as the following analysis of a sample collected from the vicinity of Mineral Point shows. This sample is low in alumina, magnesia, and silica and high in lime and differs from the material of the corresponding bed near Johnstown:

Analysis of cement rock, Mineral Point.

[Sample collected by Lawrence Martin near Mineral Point. Analyzed at structural-materials laboratory, United States Geological Survey, St. Louis. A. J. Phillips, analyst.]

Silica (SiO_2)	4.97
Alumina (Al_2O_3)	2.57
Ferric oxide (Fe_2O_3)	.56
Manganese oxide (MnO)	.48
Lime (CaO)	48.36±
Magnesia (MgO)	1.21±
Sulphuric anhydride (SO_3)	.13
Alkalies Na_2O	.08
Alkalies K_2O	.53
Water at 100° C.	.09
Ignition loss	41.17

The addition of clay or shale of proper composition would be necessary to bring rock of the composition shown above to that of a Portland cement. It is almost certain that suitable clay or shale exists in the locality. The comparative thinness of the bed will militate against its extensive use. After it has been worked some time along its outcrop it will have to be mined underground. The expense attached to such operations would prevent competition except for purely local purposes.

BUILDING STONE, PAVING BLOCKS, AND CONCRETE MATERIALS.

The only rock suitable for building stone in the Johnstown quadrangle is sandstone, and of this rock there is a great abundance. Locally it has proved of great value in the construction of culverts, bridges, etc., along the Pennsylvania Railroad and in the construction of dwellings; but as a rule it will not bear the cost of very distant transportation. The gate at the entrance to Grandview Cemetery, Johnstown, is an example of the application of this local rock for construction purposes.

The sandstones of the Conemaugh have been used in certain parts of the quadrangle in the construction of dwellings. In the northeastern part the Morgantown ("Ebensburg") sandstone member has been so used with very satisfactory results. In the hills about Johnstown the Mahoning sandstone member is exceedingly massive in places and is capable of furnishing dimension stone of sizes suitable for the foundations of houses and for culverts, bridges, chimneys, etc. A great deal of this sandstone has been quarried from the outcrops of the Mahoning sandstone member, especially in the hills east of the city, and used for the purposes enumerated.

The Pottsville formation is made up almost entirely of sandstone. It has been quarried along the main line of the Pennsylvania Railroad and used for construction purposes and in the manufacture of concrete. The Conemaugh Stone Company formerly quarried it for use in construction along the Pennsylvania Railroad from a quarry on the south side of Conemaugh River, a few miles southeast of Conemaugh Furnace. The Pottsville formation outcrops along the Pennsylvania Railroad also near South Fork, Mineral Point, and east of Johnstown, also on the Baltimore and Ohio Railroad near Paint Creek and farther south. The sandstone is in most of these localities a pure coarse-grained or gritty rock, usually weathering to a gray or gray-white rock of pleasing appearance. It seasons rapidly and firmly and withstands the eroding action of the elements in a manner to make it of great value as a building stone.

West of Coopersdale the sandstones of the Pottsville formation are quarried and crushed for use in concrete. The quarry is owned by A. B. Cooper, who also controls a quarry on the Loyalhanna limestone member in the lower part of the hill. The limestone is crushed for use in concrete and is also used for paving blocks. The quarry on the sandstone is located a few hundred feet above the tracks of the Pennsylvania Railroad on the north side of the river. The sandstone is very pure and is decidedly coarse grained to gritty in texture. It is blasted out without much regard to the size or shape of the product, the only requirement being that the fragments be as small as possible. The larger pieces are broken up and the stone is removed to the mill on the railroad by means of small cars moving on an inclined plane and controlled by a stationary engine at its foot. At the mill the sandstone is crushed by two crushers having a capacity of 100 and 300 tons a day of ten hours. It is then conveyed to a wet pan, in which it is further reduced in size and thence passed through screens of the proper size, from which it is conveyed by a bucket conveyor directly to the cars.

Another rock used in the manufacture of concrete is the Loyalhanna limestone member, which (see p. 29) occurs at the top of the Pocono formation. It is about 45 feet thick in the Johnstown quadrangle. It is not a true limestone but rather a sandy limestone. It weathers in a peculiar and characteristic way, well shown in Plate VI, *A*, page 28. This siliceous limestone is quarried and split into paving blocks which give satisfaction, and is crushed for use as ballast in railroad beds. For both uses it is well adapted, as its calcareous portion on solution and recrystallization tends to bind the fragments solidly together and yet leaves sufficient space between them to allow the free circulation of water. The siliceous limestone exposed near the viaduct between Mineral Point and South Fork has also been quarried for paving blocks.

GLASS SAND.

The question has been raised whether the pure sandstone occurring in the Pottsville formation in the Johnstown quadrangle might not be used in the manufacture of glass, especially bottle glass. Sand or crushed sandstone, as is well known, is the major constituent of glass, forming from 52 to 65 per cent of the mass of the original mixture, or from 60 to 75 per cent of the finished product. To the sand is due the absence of color (according to its purity), the transparency, brilliancy, and hardness of glass. For the finest flintware, such as optical and cut glass, only the purest sand can be employed. For plate and window glass, which are commonly pale green, absolute purity is not essential, but generally the sand should not carry more than 0.2 per cent of iron oxide. Green and amber glass for bottles, jars, and rough structural work can be made from sand relatively high in impurities, but an excess of iron is to be avoided by careful selection. Washing may be necessary to remove the iron, and magnetic separation may have to be employed. Clay in the raw material is objectionable, as it clouds the glass, but it may be removed in part by washing. Magnesia is troublesome because it makes the batch difficult to fuse. If a sandstone is used as a source of glass sand, it should be friable, so as to be readily crushed.

The sandstone derived from the Pottsville formation is in its original form a massive rock, in some places friable but in others not; the less friable portions are, however, readily crushed. In many parts of the quadrangle the sandstone of the Pottsville fills all the requirements of a glass sand for the manufacture of bottles, jars, and rough structural material; where the amount of oxide of iron is excessive it may be corrected by the addition of small amounts of manganese dioxide or other decolorizing agents. The following analysis of a sample of friable sandstone from the Pottsville formation, collected on the west flank of Laurel Ridge, not far from Seward, shows the character of this sandstone at this point, and it is quite probable that sandstone of equally great purity may be collected at other points where the Pottsville outcrops in this area:

Analysis of glass sand from Pottsville formation on west flank of Laurel Ridge, near Seward.

[Made by A. J. Phillips at the structural-materials testing laboratory of the United States Geological Survey at St. Louis, Mo.]

Silica (SiO_2)		97.54
Alumina (Al_2O_3)		.81
Ferric oxide (Fe_2O_3)		.09
Lime (CaO)		1.04
Magnesia (MgO)		.06
Alkalies	Na_2O	.02
	K_2O	.16
Water at 100° C.		.03
Ignition loss		.49
		100.24

The amount of impurities is notably small. Iron oxide falls well within the outside limits demanded for bottles, jars, and rough structural material. The amount of clayey material is very small, as is also the magnesia.

The sandstone of the Pottsville should offer no serious obstacle to being ground to the requisite fineness (say to pass through a 20 to 50 mesh sieve). In prospecting for glass sand only the clearest and whitest sand should be selected, and before exploitation complete quantitative analyses and furnace tests of representative samples should be made.

IRON ORES.

HISTORY.

But one bed of iron ore in the Johnstown quadrangle deserves mention, and that one is now of historic interest only. The interest attached to the ore is, however, great, for its presence in the hills near Johnstown was perhaps the main factor in determining the location of the present great plant of the Cambria Steel Company, which sought this position for its works owing to the close association between the ore and the underlying coal beds. With the appearance of the cheap Lake ores on the market the Johnstown iron ore ceased to be of importance. At present it is not worked, and very little first-hand information is to be obtained regarding it. The following notes are simply a compilation from the report of the Second Geological Survey of Pennsylvania [a] and are given here to make this report of the mineral resources of the Johnstown quadrangle complete

JOHNSTOWN ORE BED.

EXTENT.

The Johnstown ore bed is found in the center of the Johnstown Basin. Its eastern outcrop appears a short distance west of Conemaugh depot, where it occupies a position well up on the hillsides

[a] Rept. H2, 1875, pp. 111, 112, 118 et seq.

above the railroad. Thence it descends slowly westward, approaching water level at Hinckston Run, and after crossing the synclinical axis it again rises toward the Laurel Ridge anticline and comes to the surface on the eastern flank of Laurel Ridge. In the hills along the south bank of the Conemaugh it has never been found, although repeated search has been made for it. Its horizon has been determined may times and the vertical distance between it and the upper Freeport (Coke Yard) coal has been accurately measured. At Johnstown this interval is about 50 feet. This same iron-ore bed is known to exist on Mill Creek southeast of Johnstown, where it was benched for many years prior to 1875 by Dr. Schoenberger, the ore furnishing the material on which two small furnaces were run. The same ore was mined near and smelted at the old Cambria furnace, near the base of Laurel Hill.

CHARACTER OF THE ORE.

The ore bed at the opening of the Cambria Company's mine on the west bank of Hinckston Run was divided into two bands by a stratum of fire clay or shale which ranged from an inch to a foot in thickness and which crumbled when exposed to the weather, losing its water slowly and changing in color. The upper bench was much richer in iron than the lower, the latter being calcareous; but the ore from both benches contained sufficient lime to flux and was charged into the furnace with the coke without limestone. The ore yielded about 30 per cent of metallic iron when carefully treated in the furnace, but sometimes ran below this figure and occasionally rose above it. Its character is expressed by the following analyses, furnished by T. T. Morrell:

Analysis of iron ore from Johnstown bed.

Silica	4.885
Alumina	1.552
Carbonate of iron	52.330
Sesquioxide of iron	15.230
Carbonate of lime	15.285
Carbonate of magnesia	9.390
Phosphoric acid	.530
Sulphur	.850
Water.	
Metallic iron, 35.930.	

Mr. Morrell reports finding also a strong trace of manganese. The ore was calcined before being used in the furnace; the calcination was carried out in large open heaps near the mine, at an expense of about 10 per cent of fuel. The following analyses by Mr. Morrell show the general character of the ore after calcining, from both the upper and lower benches:

Analysis of calcined iron ore from Johnstown bed.

	Upper bench.	Lower bench.
Peroxide of iron	77.64	45.86
Silica	7.34	21.94
Alumina	1.02	4.02
Sesquioxide of manganese	1.39	.86
Lime	10.10	19.94
Magnesia	1.01	6.35
Phosphoric acid	.99	.53
Sulphuric acid	.52	.33
	100.01	99.85
Metallic iron	54.350	32.110
Phosphorus	.424	.232
Sulphur	.210	.133

PHYSICAL FEATURES OF THE ORE BED.

The ore bed is invariably underlain by shale and the roof is chiefly of the same material, being locally replaced by massive sandstone containing lumps of carbonate ore. The roof shale shows a decided tendency to crumble, and after the ore has been removed it sinks steadily, gradually reducing the height of the gangways. This behavior of the roof has been a source of constant annoyance, and has required the closest watching to avoid accidents. To counteract the sinking, "shanties" 4 feet high, consisting of strong timbers laid crosswise, are constructed at short intervals. In places these powerful logs are crushed so tightly together as not to exceed 2 feet in height. The irregularities of the bed are perhaps one of its most striking features. These irregularities consist of "rolls" and "horsebacks," which, though numerous, do not interfere with the general plan of working the ore. The system employed in mining is known as the long-wall method, the best and most economical of all systems wherever practicable. (See pp. 105–112.) By this method the ore is taken from along a line of wall which as it advances includes within a certain distance all the ore under the hill as far as the point reached.

The ore oxidizes rapidly at the outcrop, changing from a dove color to a rich brown, the former being the color of the unaltered carbonate, the latter of the hydrous oxide, or limonite, resulting from the oxidation of the carbonate. The average thickness of the ore at the Hinckston Run mine is about 2 feet; it changes, however, in thickness abruptly, the upper band thickening and the lower thinning, and vice versa. The following measurements made at different points in the mine serve to show the varying thickness of the ore bands. The third section was measured at a distance of 10 feet from the place where the second measurement was made, and the fourth 15 feet still farther southwest.

Sections of Johnstown ore bed.

	Ft.	In.
(1) Sandstone with bowlders of ore.		
Ore		5
Indurated fire clay		5
Ore		7½
Shale.		
(2) Shale roof.		
Ore, parted by 1 inch of fire clay	2	4
(3) Shale roof.		
Ore	1	2
Shale floor.		
(4) Shale roof.		
Ore	1	
Parting		4
Ore	1	
Shale floor.		

WATER RESOURCES.

The Johnstown quadrangle is a well-watered region. Most of the towns derive their water from the headwaters of the smaller creeks flowing into the main drainage channels—Stony Creek, Conemaugh and Little Conemaugh rivers, and Blacklick Creek with its North and South branches. These streams are fed by multitudes of springs as well as by the ordinary rainfall. This water is stored in reservoirs to insure a constant and adequate supply. The water is excellent, because the slopes from which most of it comes, though of small extent, are in general well wooded and comparatively free from habitation. The city of Johnstown obtains its water chiefly from three storage reservoirs, two on Mill Creek and one on Dalton Run. South Fork obtains its supply from a storage reservoir on Sandy Run. The town of Wehrum procures water from a reservoir on Rummel Run, and it is understood that the town of Vintondale also has a reservoir on a stream to the southeast. The town of Windber and associated mining villages, lying in part within the Johnstown quadrangle, are supplied partly from a storage reservoir on Little Paint Creek. For industrial purposes the Cambria Steel Company has constructed a large reservoir on Hinckston Run. During most of the year the flow of the streams is fairly adequate, but during the dry season of the autumn the supply is likely to run low. During the summer of 1906 the streams all maintained a good flow of water.

Away from the railroads the inhabitants of the region depend mostly on wells. Many of these wells have been driven as far down as coal beds, which are almost universally in water-bearing zones. The water obtained from such beds is commonly sulphurous and generally considered very wholesome. Springs are very abundant but do not appear to be large. The springs generally issue from coal beds or just above impervious clay beds. Though the volume in most such springs is not large, in purity the water can not be excelled. Many of the drill holes put down in this area have tapped water-bearing beds, but almost all the drillings have been made in search of coal beds, and little or no attention has been paid to the water-bearing strata. These usually have been either sandstone beds or coal beds. Such a hole was drilled near the confluence of North Fork and South Fork of Bens Creek in Somerset County, near Mishler. The locality is known as Sulphur Springs. The water probably issues from the Upper Kittanning coal bed, as the drill hole is understood to be very shallow.

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FRED H. MOFFIT

AND

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PREFACE.

By Alfred H. Brooks.

The completion in 1908 of the reconnaissance surveys[a] of the two copper belts lying north and south of the Wrangell Mountains paved the way for more detailed investigations. As the southern or Chitina copper belt will be the first one to be developed, it was appropriate to begin the detailed investigation in this field. The funds available for this work made it possible to survey only a part of the Chitina belt, and after careful consideration it was decided to take up the work in the Nizina district. This conclusion was based on three considerations: (1) The information available indicated that the Nizina district afforded the best opportunities for solving the general geologic problems relating to the entire copper belt; (2) the mining developments of this part of the district were more extensive than elsewhere in the belt, which gave both better opportunities for observations on the occurrence of the ores and greater promise of soon reaching a productive basis; (3) investigation of this field made it possible to cover a placer district long productive in a small way and giving promise of larger output.

The descriptions set forth in this report apply to only about one-fourth of the Chitina copper belt, but the conclusions advanced as to occurrence of the ores will, it is believed, have value to the entire district. If the developments in the Chitina Valley continue, as is expected, further surveys will be undertaken as soon as circumstances permit.

The cost of detailed geologic maps is much increased by the fact that they must be preceded by detailed topographic surveys. The Nizina region was surveyed by D. C. Witherspoon in 1908, and the resulting map, which is an excellent piece of work done under very adverse conditions, accompanies this report (Pl. II, in pocket) and adds much to its value.

[a] Moffit, F. H., and Maddren, A. G., The mineral resources of the Kotsina-Chitina region, Alaska: Bull. U. S. Geol. Survey No. 374, 1909; Moffit, F. H., and Knopf, Adolph, The mineral resources of the Nabesna-White River district: Bull. U. S. Geol. Survey No. 417, 1910.

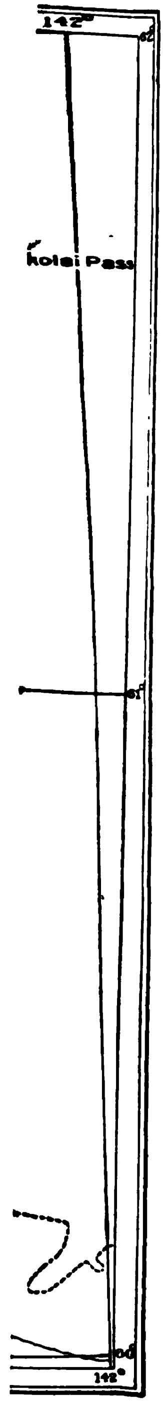
The general geology of this district as set forth in the report bears testimony to the accuracy of the observations and deductions of the earlier workers in this field. It is a significant fact that the stratigraphic subdivisions, suggested by Oscar Rohn, who did the pioneer work in this field, have found acceptance in the present analysis of the geologic sequence.

The most important conclusion bearing on the economic geology here presented is the fact that the copper-ore bodies appear to occur chiefly along a system of cross fractures which are at approximately right angles to the greenstone-limestone contact. These fractures occur along well-defined faults, at least one of which has been traced for a long distance. This may apply to the entire Chitina district and is worthy of consideration by the prospector.

These investigations also appear to indicate that the copper deposits are by no means confined to the immediate vicinity of the limestone-greenstone contact, as has usually been supposed. Though the most promising ore bodies thus far found do occur in this contact, evidence of strong mineralization has been found at a considerable distance from it. Another important fact brought out by this investigation is the occurrence of auriferous deposits in the Kennicott formation (Jurassic).

This report, although far more complete than any other report previously published on the district, is by no means exhaustive. With the progress of mining many facts will be ascertained which will make possible more definite statements on the geology of the mineral deposits. If the district develops into a great copper producer, a detailed study of the mining geology should be undertaken similar to those made of many of the mining camps of the Western States.

PLATE I



AL MAP.

GEOLOGY AND MINERAL RESOURCES OF THE NIZINA DISTRICT, ALASKA.

By Fred H. Moffit and Stephen R. Capps.

INTRODUCTION.

LOCATION AND AREA.

The Nizina district takes its name from Nizina River, a northern branch of Chitina River, and lies in the eastern part of the Copper River drainage basin. Its position with reference to the coast and the Canadian boundary is shown on Plate I, opposite. That portion of it to which the following descriptions are confined is included between parallels 61° 12′ and 61° 37′ north latitude and meridians 142° 22′ and 143° west longitude and is represented on the Nizina special map. (See Pl. II, in pocket.) The area mapped, however, is irregular in outline and only 300 square miles in extent, so that it comprises little more than one-half of the quadrangle indicated.

OUTLINE OF GEOGRAPHY, GEOLOGY, AND EXPLORATION.

Chitina River rises in the high snow-covered mountains northwest of Mount St. Elias and adjacent to the international boundary line and flows westward between the Chugach and the Wrangell mountains till it unites with Copper River at a point 100 miles from the coast. (See Pl. I.) Most of its waters, however, are derived through its northern tributaries from the snow fields of the Wrangell group. Nizina River is the largest of these tributaries. It drains the southeastern part of the Wrangell Mountains and a small part of the area between Chitina River and the head of White River. From its principal source in Nizina Glacier it flows southward for 15 miles and then turns abruptly to the west and continues in that direction 20 miles farther before joining the Chitina. It therefore has a length of 35 miles, all minor curves and irregularities of its course being disregarded. The big westward bend of the river lies almost in the center of the area covered by the Nizina special map.

The two branches of the Nizina, with Chitistone and Kennicott rivers, contribute much the greater part of its waters. It is therefore chiefly of glacial origin. All these streams are swift and heavily laden with glacial débris. They have floored their valleys with broad gravel flats, over which they migrate from side to side, sometimes in a single channel, sometimes in a network of channels, and, besides building up their flood plains by the addition of new material, they are continually cutting away and redepositing the material already laid down. The principal small streams shown on the Nizina special map are McCarthy Creek, a tributary of Kennicott River, and Dan, Chititu, and Young creeks, eastern tributaries of Nizina River. Their valleys do not show such profound glacial erosion as the main streams, for the ice masses that occupied them were smaller, yet they nevertheless underwent extensive glaciation. All are characterized by broad, open valleys at their heads and by rock canyons in their lower courses.

The Wrangell Mountains, although a more or less distinct group, merge into the St. Elias Range on the southeast and are not there sharply defined from them. They are limited on the south and west and partly on the north by the valleys of Chitina and Copper rivers, and are separated from the Nutzotin Mountains on the northeast by a depression extending from the head of Copper River to the head of White River. The group trends in a northwest-southeast direction and its length is approximately double its width. Its greatest diameter is about 100 miles. Half a dozen or more peaks of unusual beauty and size, ranging in height from 12,000 to 16,200 feet, rise above the rugged snow-covered mass about them, and from one of these, Mount Wrangell, the group received its name. The Wrangell Mountains were formed by the erosion of a great mass of Tertiary and Recent lavas piled up on an older surface of very considerable relief and having its greatest development in the neighborhood of Mount Wrangell and Mount Sanford. The southeastern limit of these younger flows is probably somewhere in the vicinity of Skolai Pass and Chitistone River, although it is possible that they may extend still farther to the east. Thus the Wrangell Mountains consist essentially of lava flows and are distinct in their origin from the other mountains about them, all of which are made up principally of deformed sedimentary beds. The area shown on the Nizina special map is on the border line between the volcanic flows of the Wrangell Mountains on the northwest and the older sedimentary formations of the Chugach and St. Elias mountains on the south and southeast, but the rock formations developed in the area are mostly of sedimentary origin.

The formations represented on the accompanying geologic map (Pl. III, in pocket) are shown in the section forming figure 1. At the base is the Nikolai greenstone, made up of a great but unknown thickness of basaltic lava flows, many of which are amygdaloidal. On the top of these flows rests the Chitistone limestone, which was deposited without any interruption of structural uniformity between it and the underlying rocks. Its thickness exceeds 3,000 feet. The lower part of the Chitistone formation consists of thick, massive beds of gray limestone, but toward the top the limestone beds become thinner and small shale beds appear in increasing amount till they finally predominate. The Chitistone limestone thus passes by transition through thin-bedded shales and limestones into a black shale with only occasional thin limestone beds. Much of the shale was removed by erosion before the deposition of the succeeding formation, so that its thickness, though in doubt, can not be less than several thousand feet. Both the Chitistone limestone and the conformably overlying shales (McCarthy shale) are of Upper Triassic age.

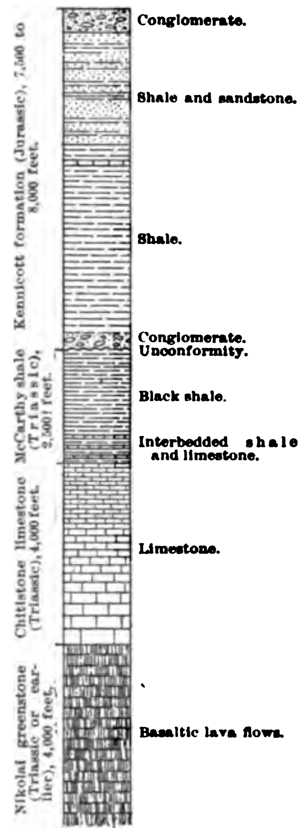


FIGURE 1.—Columnar section showing the formations represented on the geologic map of the Nizina district.

A period of uplift and erosion took place after the Triassic black shales were laid down and was not terminated till Upper Jurassic time, when deposition began once more. On the upturned edges of the Nikolai greenstone, the Chitistone limestone, and the overlying Triassic shales a great thickness of Upper Jurassic sediments (Kennicott formation) was deposited. They consist of conglomerate, sandstone, and black shale, but the shale predominates greatly over the conglomerate and the sandstone. The Jurassic sediments attain a thickness of at least 7,500 feet. They are the youngest of the bed-rock formations exposed within the mapped area. The later deposits consist of Quaternary sands, gravel, and silt, most of which are intimately connected in origin with the recent glaciation of the country.

The Nizina district has been the scene of igneous activity from Paleozoic time to the present. A great quantity of quartz diorite porphyry in the form of sills and dikes was intruded into the Jurassic rocks, but for some reason these intrusives rarely appear in the underlying formations. In some places the porphyritic intrusives are so extensively developed that they predominate over the shale, and the shale appears only as great black masses caught up in the light-colored intrusive rock.

Folding in greater or less degree has taken place in all the formations mentioned, but is far more pronounced in the older ones, particularly the Triassic shales, than in the Jurassic sediments. Within the area of the Nizina special map the greenstone, limestone, and shale formations dip rather steeply to the northeast. The Jurassic rocks, on the other hand, are tilted to the southwest or lie in broad, flat folds. All have been faulted and show local displacements of very considerable extent.

The earliest references to the geology of the Chitina Valley are found in the accounts of exploring expeditions made by Allen in 1885 and by Schwatka and Hayes in 1891. Such accounts, from the nature of the expeditions, could give only very incomplete information. The investigations by Rohn in 1899, however, laid the foundations of our present knowledge of the geology of the region. He recognized the formations that have been described and proposed the names Nikolai, Chitistone, and Kennicott. He also applied the name McCarthy Creek shale to the shale formation overlying the Chitistone limestone; but this was not adopted by Schrader and Spencer in their later work, since they believed that the shale should be divided into a number of formations.[a]

In 1900 Schrader and Spencer carried on a much more extended investigation of the geology and mineral resources of the Chitina Valley, and at the same time a topographic reconnaissance map was made by Gerdine and Witherspoon which was used as a base for the geologic map. Two years later (1902) Mendenhall visited the Kotsina and the Elliott Creek copper prospects, in the western part of the Chitina Valley, and published also some brief statements concerning the Nizina gold placers, although he had no opportunity to examine them in person. No further geologic work in the Chitina region was undertaken by the Federal Government till 1907, when interest in the copper resources of the country led to an examination by Moffit and Maddren of all the copper prospects in the valley, which resulted in some additional information concerning its geology and the occurrence of both copper and gold. The importance of the district led to the preparation of the Nizina special map by Witherspoon in 1908 and to the detailed geologic investigations in 1909, whose results are described in this report.

Many notes on the copper prospects, particularly the Bonanza mine, have appeared in the daily press and in mining magazines, and although most of them had only a temporary value as news a

[a] Schrader, F. C., and Spencer, A. C., The geology and mineral resources of a portion of the Copper River district, Alaska: Special publication U. S. Geol. Survey, 1901, note at bottom of page 32.

few are permanent contributions to the literature. An incomplete list of papers on the district follows:

ALLEN, Lieut. HENRY T. Report of an expedition to the Copper, Tanana, and Koyukuk rivers, in the Territory of Alaska, in the year 1885. Washington, Government Printing Office, 1887.

HAYES, C. WILLARD. An expedition through the Yukon district: Nat. Geog. Mag., vol. 4, 1892, pp. 117–162.

ROHN, OSCAR. A reconnaissance of the Chitina River and Skolai Mountains: Twenty-first Ann. Report U. S. Geol. Survey, pt. 2, 1900, pp. 393–440.

SCHRADER, FRANK C., and SPENCER, ARTHUR C. The geology and mineral resources of a portion of the Copper River district, Alaska: Special publication of the U. S. Geol. Survey, 1901.

MENDENHALL, WALTER C., and SCHRADER, FRANK C. The mineral resources of the Mount Wrangell district, Alaska: Prof. Paper U. S. Geol. Survey No. 15, 1903.

MENDENHALL, WALTER C. Geology of the central Copper River region, Alaska: Prof. Paper U. S. Geol. Survey No. 41, 1905.

MOFFIT, FRED H., and MADDREN, A. G. The mineral resources of the Kotsina and Chitina valleys, Copper River region: Bull. U. S. Geol. Survey No. 345, 1908, pp. 127–175. (This is a preliminary statement of results published in a more complete form in Bulletin 374.

KELLER, HERMAN A. The Copper River district, Alaska: Eng. and Min. Jour., vol. 85, No. 26, June, 1908, pp. 1273–1278.

MOFFIT, FRED H., and MADDREN, A. G. The Kotsina-Chitina region, Alaska: Bull. U. S. Geol. Survey No. 374, 1909.

The field work on which the present report and the geologic map are based was done between July 1 and September 10, 1909, or in a little less than seventy days. It was greatly aided by a previous knowledge of the region and by the earlier work of Schrader and Spencer, but the time available was too short to permit an excursion up Nizina River to determine the relation between the Triassic and the Paleozoic sediments on Skolai Creek, or to make a careful study of the Kennicott formation south of Young Creek. Both localities merit careful investigation because of the light they may throw on the stratigraphy of the region. The chapter in this report dealing with the Quaternary system was written by Mr. Capps, who also did the office work on the geologic map. The task of preparing the remainder of the description of general geology and of economic geology fell to the senior author.

CLIMATE.

The climate of Chitina Valley is pleasanter in many ways than that of the Pacific coast region of Alaska. Temperature variations are far greater, but the precipitation is less and the number of cloudy, disagreeable days is very much smaller. No continuous records of temperature and precipitation are at hand, and it is probable that none have been kept, although observations for parts of several years have been made at Kennicott and were made available through the kindness of Mr. Stephen Birch.

The Copper River region, of which Chitina Valley is a part, as has been stated previously, is separated from the Pacific coast by a broad belt of mountains nearly 50 miles across and ranging in height from 6,000 to 10,000 feet. This belt is broken only by the narrow canyon-like valley of the lower Copper River, and by its influence on the warm moisture-laden air of the Pacific it becomes an important factor in the climate of Copper and Chitina basins. Another factor of importance is the still loftier Wrangell group of mountains on the north.

The seasons of Copper River basin are a long winter and a short summer, separated by a still shorter spring and fall. Spring comes sooner in the upper Chitina Valley than in the Copper River valley proper, as is shown by the earlier breaking up of the ice. Snow goes from the valley bottoms by the middle of May and from the lower hills by the first of June, but enough remains on the mountain sides till the first or middle of July to hinder prospecting. The summer climate resembles that of some of our Northern States in late spring. Frosts are not expected from the middle of June to the middle of July, but by the first of September the snow line begins to descend on the mountain sides. After the spring break-up the volume of water in the streams, particularly those fed by snow fields and glaciers, gradually increases until it reaches a maximum about the middle of July; it then decreases rapidly as the cooler nights come on. The July period of high water is not the result of increased precipitation but of the warm weather and the bright sun on the snow fields. Cloudy days always make a very appreciable difference in the daily rise of the glacier streams. Sometimes, however, the rivers are flooded by unusually heavy rains and occasionally in winter by the breaking out of water confined in the glaciers. This took place in the Kennicott Glacier early in 1909. During a period of unusually cold weather the outlet of the subglacial stream known as the "pot-hole" was closed and the water backed up under the glacier till the pressure was so great that the ice could not resist it. The water burst forth from a new outlet and flooded the Kennicott and Chitina rivers, tearing up the ice and piling it in confusion. Fortunately no one was freighting on the river, and the new ice which formed afterward gave the best sledding ever known by freighters on the Chitina. A similar flood caused by the breaking out of confined waters from Nizina Glacier took place a few years previously. The high water of July makes the fording of Nizina River difficult and at times dangerous, but this difficulty decreases in August, and by the first of September it is ended. Temperatures low enough to allow standing water to freeze are usual in the latter part of August, and early in September the glaciers cease to be active and the streams are clear and low.

Temperatures of 30°, 40°, or even 50° below zero are experienced in winter, and the snowfall is heavy, although much less than on the coast.

Observations at Kennicott, at the mouth of National Creek, and at the Bonanza mine, a little more than 2½ miles away and 4,000 feet higher, showed that the temperature at the mine during the coldest weather was always considerably higher than at the lower camp.

The winter of 1908–9 was unusual because of its low temperatures and light snowfall. It resulted from these conditions that the streams were in places frozen to the bottom, and the water, breaking out above, ran down over the top and froze to a great thickness. Some of the so-called glaciers on Chititu Creek had a thickness of 15 or 20 feet and did not melt away till early in the following July, thus seriously interfering with placer mining. Such conditions are common enough in the streams of northern Alaska but are unusual in the Nizina district.

VEGETATION.

In this region, as in many other parts of Alaska, vegetation flourishes in a way that would be surprising to those who think of the country only as a region of continual cold and ice. The growing season is short, but the summer days are warm and much longer than in lower latitudes, so that in the few favorable weeks plants grow rapidly. Grass comes up as soon as the snow goes and by the first or middle of June there is good feed for horses in favorable places. It is not abundant in the lower valley bottoms, even in midsummer, and the best of it is found at or above timber line. There is good feed in the upper part of all the small valleys. A small leguminous plant, locally called "pea vine," grows on the gravel bars and in the fall and late summer makes excellent forage. It is nourishing, and horses are so fond of it that they will leave almost anything else to get it. Grass loses its nourishing qualities as soon as the frost strikes it, and for this reason miners and prospectors start their horses to the coast about the first of September.

All the lower mountain slopes of the Nizina district and all the valley bottoms except the flood plains of streams are covered with spruce timber. The upper limit of timber ranges from 2,500 to 4,000 feet above sea and is highest on the gentle and rounded slopes away from the glaciers, such as the south slope of the ridge west of Rex Creek and on Sourdough Hill. Timber suitable for lumber grows on the lower ground. The best of it is found on the flats south of Nizina River, from Dan Creek to Young Creek, in the drier ground at the base of the hill slopes. Some of the trees reach a diameter of 18 inches and are tall enough to furnish two 16-foot cuts. Besides the spruce, there are cottonwood and birch, but these have little value for lumber. A heavy growth of alders is usually found about timber line. Willows are present in the valleys, but are far less abundant in variety and amount than in northern Alaska. The "devilclub," so troublesome in the coast region, is found occasionally in the Nizina district also.

POPULATION.

During the early days of the Nizina gold excitement the white population of the district amounted to several hundred persons, but this number quickly decreased, as is usual in such stampedes. There are no accurate records of the number of early comers. Some of them were of the "hanger-on" class and stayed only long enough to learn that the district had little to offer them. The later population has been a variable one, but for the last two or three years it probably has not been far from 100. Most of this number were employed in the gold placers of Chititu and Dan creeks and the rest were prospecting for copper. With the completion of the railroad and the beginning of mining at Kennicott and the increased activity in the gold-producing streams that will come with better transportation the white population will increase. There is no permanent native population. Nizina River valley was the hunting ground of Chief Nikolai, and his house was near the mouth of Dan Creek, but since his death several years ago superstition has kept his followers from returning there until within the last two summers. The permanent dwellings of the Indians are on Copper River, where they spend most of the winter and where they fish in summer. It seems to have been the custom of many to leave the fishing ground only during the time of the fall hunting or in the trapping season.

TRANSPORTATION.

To provide satisfactory means and routes of transportation has been from the beginning the most serious difficulty the prospectors in Chitina Valley have had to meet. Up to the present time all supplies and equipment for the Nizina district have been brought from Valdez in winter by sled. The route usually followed in freighting is from Valdez to Tonsina over the Government trail, then by way of Tonsina, Copper, Chitina, and Nazina rivers to the destination. Occasionally, however, this route has been varied by crossing Marshall Pass at the head of Lowe River and following Tasnuna and Copper rivers to the mouth of the Chitina; but this latter route was given up because of the difficulties encountered on Tasnuna River and of the fact that the Government trail to Fairbanks is kept open all winter by the regular travel. The great advantage of the route lay in the ability to haul very heavy loads on the smooth ice of Copper River, thus saving time and horse feed, the two great items of expense, on this part of the trip. This route probably would have been used exclusively for freighting to Chitina Valley if a good trail down Tasnuna River had been available for travel.

The time consumed in carrying large outfits from Valdez to the Nizina district is from two to three months. The cost of freighting has varied from slightly less than 7 cents to 30 cents per pound, depending on the size of the outfit and the condition of the trail. The lower figure of cost is an exceptional one and is not possible under any other than the most favorable conditions. Probably about 10 cents per pound is an average cost for the larger companies when the trail is good.

Summer travel is over a route different from that followed in winter. The summer trail leaves the Government trail at Tonsina and crosses Copper River at the mouth of Tonsina River. From there it passes to the north side of Chitina Valley, entering the mountains by way of Kuskalana River and crossing Kuskalana and Fourth of July passes to Kennicott Glacier and River. No freighting is done on the summer trail, but the mail goes in over it twice each month.

Within the Nizina district trails connect the various camps and enable the miners to travel from one to another without serious difficulty, although there is little communication between them during the working season. The trails are all shown on the topographic map and need not be described in detail. The one most traveled is that over Sourdough Hill from McCarthy Creek to Chititu and Dan creeks. Because it is less swampy, it is used by many in preference to the lower trail around the west end of the hill, but the hill is steep and the climb is hard. One great difficulty with this trail is the necessity of fording Nizina River. A proposal to bridge the river at a point several miles below the present fording place will probably be carried out in the near future.

It is seen from the figures previously given that the cost of transportation is a heavy tax on all work done in the Nizina district. This expense has not only hindered copper prospecting but has delayed the installation of placer mining machinery also. This burden will be much lightened in a short time, however, for railroad communication with the coast is promised early in 1911. Construction work on the Copper River and Northwestern Railway was commenced under the present management at Cordova in 1908 and since that time has been pushed as rapidly as conditions permitted. In 1908 the tracks were advanced from Cordova to within 10 or 12 miles of Abercrombie Rapids, although the lower steel bridge over Copper River was not erected till the following spring. In 1909 the piers for a second bridge, at the river crossing between Childs

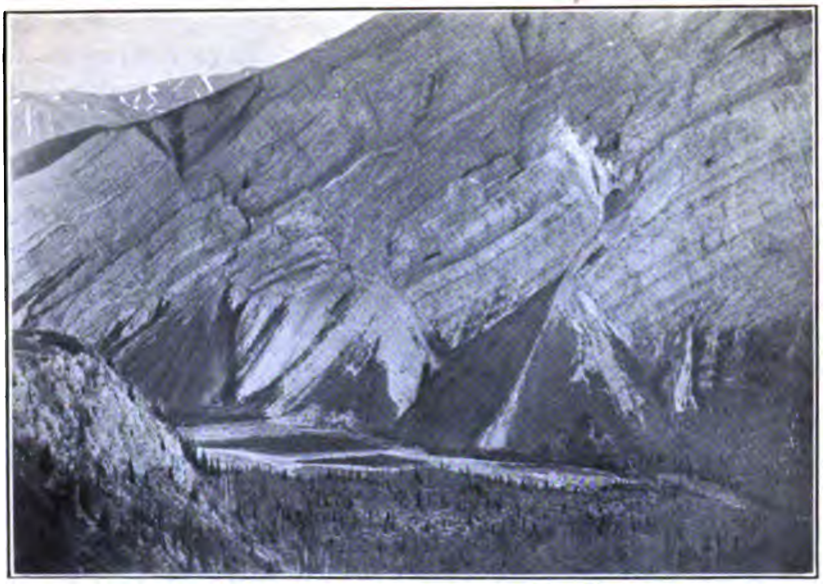
Glacier and Miles Glacier Lake, were built and the tracks were advanced to Tiekel River. With the completion of this part of the road most of the slow and difficult work was ended and there remained only 90 miles of track construction to reach Kennicott. This includes a third bridge over Copper River, between the mouths of Chitina and Kotsina rivers, where it is proposed to place a temporary pile bridge while the construction of piers for the permanent bridge is going on. The building of the railroad has not involved any unusually difficult construction problems for modern railroad engineering, and the greatest obstacles to operation will doubtless arise from weather conditions. Along Copper River the tracks are particularly exposed to obstruction by snowslides, and adequate provision for their protection will have to be made. Above Abercrombie Rapids the tracks follow the river bank on the débris-covered edge of Baird Glacier. The ice is overlain by a thin coating of loose rock and is overgrown with alders. It appears to have no motion, but it is probable that more or less melting goes on and that the tracks will require more attention and repair than in other places. Some have expressed uncertainty concerning the effect of the terrible winter winds that sweep down the lower part of Copper River valley and have even predicted that they would prevent the running of trains, but such difficulties have been overcome elsewhere and probably will be here. Railroad communication with the coast promises greater aid in the development of the Copper River valley than any other single enterprise yet undertaken.

TOPOGRAPHY.

RELIEF.

The Nizina district has been described as situated at the southeastern border of the Wrangell Mountains, in the region where this group merges into the Coast Range Mountains to the east and south. The mapped area does not extend far enough north or east to take in any of the larger snow fields or glaciers or to include the highest mountains of the Wrangell group or Coast Range, although peaks of 7,000 or 8,000 feet are shown. To the southeast is the broad lowland formed by the junction of Chitina and Nizina valleys. The map (Pl. II, in pocket) shows as the major features of relief two mountain areas separated by the valley of Nizina River, but other topographic forms are even as striking as these, particularly the steep, straight valley walls, the deep gulches tributary to Young Creek, and the peculiar wormlike rock glaciers.

Three geologic elements are involved in the relief—the high mountain masses, the gravel-covered lowlands, and the gravel benches or terraces. Glacial erosion and the character of the rock formation have



A. TALUS CONES ON EAST SIDE OF McCARTHY CREEK, AT BASE OF LIMESTONE CLIFFS.

See page 19.

B. FOLDED TRIASSIC LIMESTONE AND SHALE BEDS ON SOUTHWEST SIDE OF COPPER CREEK.

See page 28.

been strikingly effective in giving form to the mountains. The work of the ice in straightening and steepening valley walls is conspicuous on Chitistone River and the adjacent part of Nizina River and on the upper part of McCarthy Creek. It is also seen in the numerous cirque valleys in which most of the streams head. McCarthy Creek is a typical example of a glaciated valley in this district. Its upper part is a broad, open, U-shaped valley with gravel floor. Its lower part is a succession of rock canyons with high gravel terraces. These features, except the gravel terraces, are characteristic of every glaciated valley of the region and are probably the result of rapid head valley glacial erosion and the effort of the stream to establish a more advantageous grade after the melting of the ice.

Different kinds of rock were affected in different degrees by the glacial ice and by subsequent erosion. The massive Chitistone limestone forms precipitous cliffs and tall spires, as on Dan Creek, Chitistone and Nizina rivers, McCarthy Creek, and at Bonanza mine. The greenstone slopes are not so steep and are more uniform in surface contour; they rarely form perpendicular walls such as are common in the limestone exposures. The shales give smooth, rounded outlines where they have undergone glacial erosion and sharp, jagged peaks and ridges with steep, bare slopes where they have been subjected to attack by weather alone. These two features are seen in the shale area south of Dan Creek. Between Dan Creek and White Gulch the shale mountains are characterized by angular outlines and bare slopes, but south of Chititu Creek the same shales were overridden by the ice streams from Chitina Valley and present smooth, rounded contours. This feature, however, has been modified by intense postglacial erosion, with the production of such topographic forms as Blei Gulch and the deep gashes cut by tributaries of Young Creek. A different topographic form, dependent on the structure of the upper shale formation, is the flat top of the ridge on the west side of Nizina River directly opposite the mouth of the Chitistone. It is due to the almost horizontal position of the sandstone beds that form the base of the Kennicott in this locality.

Talus deposits cover the lowest mountain slopes and reach their greatest development at the bases of large porphyry exposures and limestone cliffs. In this connection it should be said that the occurrence of a small proportion of porphyry in talus slopes and rock glaciers is usually sufficient to obscure other kinds of rock. Talus fans of noticeable symmetry have been built up below gulches in the limestone formation east of McCarthy Creek (Pl. IV, *A*) and north of Chitistone River. The peculiar detrital accumulations here called rock glaciers are confined to the high mountainous parts of the district but are widely distributed in the mapped area. They are described in the discussion of Quaternary deposits.

The second important element in the relief of the district is the gravel-covered valley lowland areas. Their distribution is readily seen on the map. They represent the accumulated deposits of present glacial erosion and the reworked deposits of former glaciation, together with the contributions of present stream erosion. With the older bench gravels they occupy fully one-third of the mapped area. The bench gravels, which are of glaciofluvial origin, are most conspicuous about the mouth of Dan Creek, the lower parts of Chititu and Young creeks, and on McCarthy Creek, but are present in other places also.

DRAINAGE.

Nearly all the larger streams of the Nizina district originating within the mountain area head in glaciers, and those that do not thus head nevertheless receive much of their water from melting snow banks throughout all or part of the year. All the streams are swift and subject to rapid variations in quantity of water flowing in them. Nizina River falls 600 feet in 19 miles within the mapped area, or at the rate of 31.5 feet per mile. McCarthy Creek has a grade of 100 feet per mile and Chititu Creek 180 feet per mile in their lower courses.

In contrast with the well-drained mountain areas, the lowlands are swampy and dotted with numerous ponds and lakes. They are covered with an inferior growth of spruce and with moss that acts like a sponge to hold water and prevent its rapid run-off. The surplus water from the lakes is carried away in sluggish clear-water streams. These features are characteristic of the southwest part of the mapped area. Trails in such country are often almost impassable for horses in summer, and for that reason they keep to the gravel bars or the ridges.

DESCRIPTIVE GEOLOGY.

STRATIGRAPHY.

SEDIMENTARY ROCKS.

ROCK TYPES.

It has already been stated that the Nikolai greenstone is the oldest rock formation exposed in the Nizina district and that it is conformably overlain by the Chitistone limestone and a shale formation (McCarthy shale), both of which are of Triassic age. It was further stated that a great thickness of shale of Jurassic age—the Kennicott formation—rests unconformably upon the upturned edges of the greenstone, limestone, and shale; that these formations, particularly the Kennicott, were intruded by light-colored porphyritic igneous rocks; and that the most recent deposits of the district are unconsolidated gravels of Quaternary age.

The Nikolai greenstone, because of its relation to the Chitistone limestone, its importance as a geologic formation, and its structure, might fittingly be described in connection with the sedimentary formations. Inasmuch, however, as it is of igneous origin, its description will be taken up later in its proper place in the account of the igneous rocks.

TRIASSIC SYSTEM.

CHITISTONE LIMESTONE.

CHARACTER OF THE FORMATION.

The name Chitistone was applied by Rohn to the great Triassic limestone of the Nizina district because he found the limestone best developed along the Nizina in the vicinity of the mouth of Chitistone River. This name was later adopted by Schrader and Spencer and has since come into general use. The Chitistone limestone is a conspicuous formation occurring all along the south flanks of the Wrangell Mountains from Kotsina River to Dan Creek and probably extending into the valley of the upper Chitina. In the Nizina district the lower part of the Chitistone formation is made up of thick, massive beds of a dark-gray or bluish-gray color but weathering to a lighter gray on the surface. The upper part, on the other hand, is made up of thinner beds, and this thinness increases toward the top. A slight difference in chemical composition between the upper and the lower parts of the Chitistone limestone is indicated by the brownish-yellow weathering of the upper part. Changing conditions of sedimentation are indicated, too, in a more noticeable way by the appearance of thin shale beds at the top of the formation. This limestone is the oldest of the sedimentary formations exposed within the mapped area and lies on the Nikolai greenstone conformably, exactly as if both were sedimentary formations deposited in the same sea and the limestone had been laid down on the greenstone before any movement or disturbance had taken place in the greenstone. This conformable relation holds true wherever the contact has been examined, although in many places it is found that there has been movement of the two formations along this contact surface. In several places a bed of red and green shale with a maximum thickness of about 5 feet was found to intervene between the limestone and the greenstone, but it is not known whether the shale is widely distributed or not, since the limestone-greenstone contact is nearly everywhere covered with talus. The shale is present in the vicinity of Bonanza mine and on Kennicott Glacier.

Excellent sections of the Chitistone limestone are seen on the west side of Nizina River, opposite the mouth of Chitistone River, and on McCarthy Creek. On McCarthy Creek the lower part of the formation, which dips about 30° NE., consists of massive beds of bluish-gray limestone, making up approximately three-fifths of the total thickness. Above this lower massive portion is a succession of more thinly bedded limestone strata weathering a rusty-yellow color and making up the remaining two-fifths of the formation. The thickness of individual beds decreases from the base toward the top, as has been stated, and near the top thin beds of black shale make their appearance. Then comes an indefinite thickness, approximately 300 feet, of thin-bedded limestone and shale overlain in turn by a great thickness of black shale, which Rohn called the McCarthy Creek shale.[a] It is thus seen that there is a transition from the bedded limestones below through interbedded thin limestones and shales to shale above, and it is readily understood that difficulty arises in choosing a definite dividing plane between these two formations.

The section on Nizina River shows the same features as that on McCarthy Creek, but here the whole syncline is exposed, revealing the steep northward dip on the south, the horizontal bedding in the middle, and the gentle southward dip on the north. The bedding features are well shown in the center of the syncline for the whole succession from base to overlying shales. (See Pl. V.)

DISTRIBUTION.

The Chitistone limestone occupies a narrow band along the northeastern edge of the mapped area, extending southeastward from Kennicott Glacier (at the northern limit of the area) to the head of Copper Creek. The dip of the limestone along its southern boundary is to the northeast and decreases from approximately 30° in the vicinity of Kennicott Glacier and McCarthy Creek to only a few degrees on Dan and Copper creeks. It results from this that the width of the limestone belt is much less at the glacier and on McCarthy Creek than on Dan Creek. The limestone belt has a width of slightly more than 1 mile on the ridge between McCarthy Creek and East Fork, which is probably less than its width at any place between McCarthy Creek and Kennicott Glacier. East of Nizina River the limestone caps the mountains between Dan Creek and Chitistone River in the form of a broad, shallow syncline fully 5 miles wide. The continuity of limestone exposures is interrupted in many places by valley gravel and talus deposits, but aside from separate limestone areas produced in this way there are a number of small detached areas whose separation from the principal limestone masses represented on the map is due to other causes. Such an area is seen at the head of Nikolai Creek and owes its isolation to the fact that the overlying Kennicott formation has been only partly eroded. If all of the conglomerate and sandstone of the Kennicott

[a] Rohn, Oscar, A reconnaissance of the Chitina River and the Skolai Mountains, Alaska: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, p. 426.

LIMESTONE WALL ON WEST SIDE OF NIZINA RIVER NEAR MOUTH OF CHITISTONE RIVER.

The limestone overlies the Nikolai greenstone on the left. See page 22.

were removed, the small limestone area would be found to be part of the larger area to the east. Another isolated area lies south of Dan Creek, but in this case the limestone was separated from the main limestone mass to the north and reached its present position through faulting.

THICKNESS.

The two localities on Nizina River and McCarthy Creek afford favorable opportunities for measuring the thickness of the Chitistone limestone, since in both places the whole formation is present. One element of uncertainty presents itself, however—the difficulty of choosing the somewhat arbitrary plane to separate the limestone from the overlying shales; yet, since the intervening thin-bedded shale-limestone succession is probably less than 300 feet thick, the error in measurement, and the results are the same as on Nizina River. A 5 per cent, as will be seen later.

The base of the limestone in the central part of the syncline on Nizina River is hidden by river gravels, but since the curve of the beds is small and regular and greenstone is exposed along the base of the cliffs only a short distance north and south of the axis of the syncline, it is evident that almost the complete section of the limestone is shown in one vertical column. This section gives a thickness of 3,000 feet for the Chitistone limestone in its type locality. The McCarthy Creek section gives an almost equally good chance for measurement, and the results are the same as on Nizina River. A section north of Chitistone River gives a greater thickness than 3,000 feet, but as in this locality the limestone has been folded and faulted it is believed that the figures there are less reliable than those first given.

Exposures of Chitistone limestone extend westward to Kotsina River, less than 15 miles from Copper River, but the thickness is much less than in the Nizina district and in places is not more than 200 or 300 feet. No evidence has been collected to show that the limestone becomes progressively thinner from the east toward the west in Chitina Valley, and, although that may be the case, the decreased thickness in the valleys of Kotsina River and Elliott Creek may be due to erosion before deposition of the Kennicott formation took place.

AGE.

The age of the Chitistone limestone was long in doubt but is now known to be Upper Triassic. This age determination is based on fossil collections made in 1907 at a number of localities along the limestone area from Kotsina River to the Chitistone and on larger collections made in the Nizina district in 1909. All the collections were submitted to T. W. Stanton for determination and the forms present are contained in the following lists. These lists include, however, only the species collected within the area of the Nizina special map. The numbers given the specimens are the catalogue numbers in the National Museum. Concerning the collection of 1907 Dr. Stanton says in part:

The collection is small and fragmentary, but it has proved sufficient to show quite conclusively that the beds in question are of Triassic age. The ammonites, especially, are all characteristic Triassic types, and the few brachiopods obtained are also Mesozoic. There is no indication of Paleozoic fossils in any part of the section represented. * * *

The following lists give the form recognized from each locality. In most cases specific identifications have not been possible, but this does not lessen the accuracy of the age determination:

Bonanza mine and Bonanza Creek:
- 4808; Nos. 9, 14 to 19, 21, 22—
  - Undetermined corals.
  - Terebratula sp.
  - Spiriferina sp.
  - Hinnites? sp.
  - Pseudomonotis subcircularis (Gabb)?

Jumbo Creek, near the Bonanza mine:
- 4809; Nos. 10 to 13, 20—
  - Pentacrinus sp.
  - Terebratula sp.
  - Avicula? sp.
  - Arcestes? sp.

  The last two named are certainly Triassic types of ammonites and probably belong to the genera to which they are provisionally assigned.

South side of Chitistone River:
- 4810: Nos. 23, 24—
  - Spiriferina? sp.
  - Halobia sp.
  - Arcestes? sp.
  - Tropites? sp.

  The last two are Triassic ammonites provisionally identified from imperfect specimens.

The list of fossils collected in 1909 is here arranged by localities. Dr. Stanton says of them:

The fossils from the Chitistone confirm the recent determinations of that horizon and definitely prove that it is of Triassic age.

Jumbo Creek:
- 6300—
  - Base of Chitistone limestone corals? Too obscure for identification.

McCarthy Creek:
- 6330—
  - Terebratula sp. Probably Triassic.

Nikolai Creek:
- 6303—
  - Halobia sp.; related to H. superba Mojsisovics.
  - Undetermined Pelecypod.
- 6306—
  - Juvavites? sp.
  - Arcestes sp.

Nikolai Creek—Continued.
- 6312—
  - Pseudomonotis subcircularis (Gabb).
  - Arcestes. sp.
  - Juvavites? 2 sp.
  - Orthoceras sp.

Chitistone River:
- 6319—
  - Tropites sp.
  - (Lower part of Chitistone limestone.)
- 6320—
  - Halobia superba.
  - Arcestes.
- 6333—
  - Halobia superba Mojsisovics?
  - Arcestes sp.

Copper Creek:
- 6321—
  - Halobia superba Mojsisovics?

When Schrader and Spencer studied the geology of the Chitina Valley in 1900 they found no fossils in the Chitistone limestone and were unable to give conclusive evidence concerning the age of the limestone. They, however, correlated it with the massive Carboniferous limestone at the head of White River, first described by Hayes[a] and later by Brooks.[b]

This limestone is exposed on the north side of Skolai Creek, one of the eastern tributaries of Nizina River, and is conspicuous in Skolai Pass, between the heads of Skolai Creek and White River. The correlation of limestones so similar in appearance and so near to each other seemed to have much in its favor, but better opportunities for study have proved it to be incorrect.

Although the Chitistone limestone can not be correlated with the limestone on White River, it is known that limestone similar in appearance and of the same age as the Chitistone limestone is present on the north side of the Wrangell Mountains, in the depression between them and the Nutzotin Mountains. There is, however, no such development of Triassic limestone there as is seen in the Chitina Valley, and the known exposures are confined to one small area.

A table of correlations for the Mesozoic sedimentary rocks of Alaska is here given, from which it appears that Triassic rocks, so far as they are known at present, are confined to the region south of the Alaska Range. Aside from the Chitina region, Triassic rocks probably have their greatest development in the Cook Inlet region, where they occur principally in the form of cherts with a small proportion of shale and limestone beds.

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[a] Hayes, C. Willard, An expedition through the Yukon district: Nat. Geog. Mag., vol. 4, 1892, p. 140.

[b] Brooks, Alfred H., A reconnaissance from Pyramid Harbor to Eagle City, Alaska: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, p. 359.

Correlation of the Mesozoic sedimentary rocks of Alaska.

		Nizina district (Moffit and Capps, 1909).	Nabesna-White River district (Moffit and Knopf, 1908[a]).	Talkeetna and Matanuska district (Paige and Knopf, 1906[b]).	Cook Inlet and Alaska Peninsula (Stanton and Martin, 1904[c]).	Alaska Range (Brooks, 1902[d]).	Southeastern Alaska (Wright and Wright, 1908[e]).	Yukon Basin (Brooks and Kindle, 1908[f]).	Northern Alaska (F. C. Schrader, 1901[g])
Cretaceous.	Upper				Marine and nonmarine shales and sandstones, conglomerates. coal.			Conglomerates, sandstone, slate, and shale, cut by granite.	Bergman series (?) Nanushuk series. Sandstones with some conglomerate, slate, and lignite.
					—Unconformity—			—Unconformity—	—Unconformity—
	Lower.			Limestone.			Shale, conglomerate limestone, graywacke and slate overlying andesitic lavas, tuffs, breccia, conglomerate, and sandstone, which in turn rest on granite intrusives.	Siliceous slate and quartzites, with some tuff and a little limestone, cut by basic dikes.	Anaktuvuk series and Koyukuk series. Feldspathic sandstones and some conglomerate. Impure limestone, sandstone, slate, and igneous rocks.
								—Unconformity—	—Unconformity—
Jurassic.	Upper.	Kennicott formation. Conglomcrate shale, sandstone.	Banded slates, graywackes, and conglomerate, with some limestone and sandstone.	Shales, sandstones, conglomerates, tuff, and arkose, with coal.	Naknek formation. Conglomerate, arkose, sandstone, and shale, with interstratified andesite flows.				Corwin series. Gray sandstone, limestone and shale, quartzite, and some coal.
		—Unconformity—	—Unconformity—	—Unconformity—					Unconformity—
	Middle.			Shales, sandstone, and conglomerate, with coal. Andesitic greenstone, tuffs, agglomerates and breccias, rhyolites, dacites, and tuffs.	Enochkin formation. Shales and sandstones, with some conglomerate beds.	Tordrillo group. Compact feldspathic sandstones and grits, slate, and some limestone.			

				Unconformity	Unconformity	Unconformity			
	Lower.				Tuffs and sandstones.				
					Unconformity				
Triassic.	Upper.	McCarthy shale, Chitistone limestone.	Limestone.		Thin bedded cherts, limestones, and shales usually much contorted and with many intrusive masses. Base not seen.	Skwentna group, age undetermined. Igneous rocks, with some slates and limestones.	Argillaceous limestones and calcareous sandstones.	Limestones and slates.	
						Unconformity			

a Moffit, Fred H., and Knopf, Adolph, Mineral resources of the Nabesna-White district, Alaska: Bull. U. S. Geol. Survey No. 417, 1910, p. 16.
b Paige, Sidney, and Knopf, Adolph, Geologic reconnaissance of the Matanuska and Talkeetna basins, Alaska: Bull. U. S. Geol. Survey No. 327, 1907, p. 10.
c Stanton, T. W., and Martin, G. C., Mesozoic section on Cook Inlet and Alaska Peninsula: Bull. Geol. Soc. America, vol. 16, 1905, p. 410.
d Brooks, Alfred H., The Mount McKinley region, Alaska: Prof. Paper U. S. Geol. Survey No. 70, 1911, p. 591.
e Wright, F. E., and Wright, C. W., The Ketchikan and Wrangell mining districts, Alaska: Bull. U. S. Geol. Survey No. 347, 1908, p. 34.
f Brooks, Alfred H., and Kindle, E. M., Paleozoic and associated rocks of the upper Yukon, Alaska: Bull. Geol. Soc. America, vol. 19, 1908, p. 263.
g Schrader, F. C., A reconnaissance of northern Alaska: Prof. Paper U. S. Geol. Survey No. 20, 1904, p. 53.

McCARTHY SHALE.

CHARACTER OF THE FORMATION.

The term McCarthy Creek shale was used by Rohn to designate the black shales immediately overlying the Chitistone limestone, and the formation was described by him as "a series of soft, black, highly fissile shales and slates."[a]

The formation as it is exposed in the Nizina district is essentially a shale formation, although at its base are numerous thin limestone beds forming part of the transition zone at the top of the Chitistone limestone or the base of the shale. Thin beds of limestone are found interstratified with the shales wherever they are exposed within the mapped area, but are not abundant and form only a small proportion of the whole. The top of the McCarthy shale has not been recognized. Bedding is easily distinguished in most places either by the presence of the thin limestones or of thin limy shale beds with surfaces highly colored by weathering. Some of the smooth bare hilltops about the eastern tributaries of East Fork are marked with exceedingly intricate patterns produced by the colored beds, for the McCarthy shale is found to be intensely folded wherever it has been examined, and if the folds are cut by planes or curved surfaces making slight angles with their axes the patterns appear.

The folding in the McCarthy shale strongly contrasts with both that of the Chitistone limestone and that of the Kennicott formation. Pronounced folding took place in the upper thin-bedded part of the limestone in a few localities. It begins to be conspicuous in the transition beds at the base of the shale (see Pl. IV, *B*, p. 18) but was never found in the massive beds at the base of the limestone. The limestone beds were more able than the shale to withstand the pressure that tended to deform them, and that ability increased as the thickness of the beds increased. Another factor of strength lay in the massive flows of the Nikolai greenstone, which lent its support to the heavy beds of the limestone in resisting deformation.

DISTRIBUTION.

The principal area of McCarthy shale represented on the geologic map (Pl. III, in pocket) lies between McCarthy Creek and Nizina River, at the north edge of the sheet. This, according to Rohn, is the south edge of a succession of shales extending north in the McCarthy Creek valley for a distance of 6 or 8 miles and constituting the type locality for the formation. This is not only the largest area of the shales examined but it also shows a greater thickness than any other area, for it suffered less from erosion before the Kennicott formation was deposited.

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[a] Rohn, Oscar, A reconnaissance of the Chitina River and the Skolai Mountains, Alaska: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, p. 426.

The McCarthy shale and the shale-limestone transition zone below it form the base of the mountains south of Copper Creek. The formation is separated from the overlying Kennicott formation by a distinct unconformity, but the black shales of the two formations are so similar in appearance that they were not distinguished until the detailed work of 1909 was undertaken. Only the base of the McCarthy shale is exposed on Copper Creek. The upper part was removed by erosion before deposition of the Kennicott began. A smaller area of the Triassic shale forms the mountain top north of Texas Creek, and the formation is present in other places overlying the limestone north of Dan Creek but does not fall within the boundaries of the mapped area.

THICKNESS.

Accurate measurements of the thickness of the McCarthy shale were not obtained, because it is probable that only a part of the total thickness is exposed within the mapped area. It is possible, moreover, that the complete original section is no longer represented in this district, for a long erosion interval intervened between the deposition of the Triassic shales and the Jurassic shales. During this interval much of the Triassic sedimentary formations and of the Nikolai greenstone was removed. Another factor of uncertainty besides the amount of the shales that have been removed by erosion is the thickening and reduplication of beds that arise from folding and faulting. It is probable, however, that the McCarthy shale has a thickness nearly as great as the Chitistone limestone; possibly it is greater.

A thickness of about 1,500 feet of Triassic shale overlies the limestone on the west side of Nizina River. The shales near the center of the broad syncline in this locality have a horizontal position and are probably less distorted by folding than they are to the northwest. This measurement is considered the minimum and probably much less than the true thickness, for some of the shale has certainly been removed by erosion.

The mountains about the head of the East Fork of McCarthy Creek are made up of the black Triassic shales. They reach an altitude of 6,960 feet above sea level or 3,000 feet above the limestone shale boundary at the creek on the southwest. The shales are much folded about the upper part of the East Fork valley, and measurements are consequently uncertain, but it is probable that the thickness of the formation is at least 2,500 feet in this vicinity. No measurements of value were obtained in the Copper Creek section, for, as previously stated, only a part of the formation is present there.

It is evident from what has been said that the total thickness of Triassic sediments in the Nizina district is great and that it is probably not less than 6,000 feet. One-half of this figure represents a limestone whose thickness can be stated with a considerable degree of accuracy; the remainder represents a great shale formation whose thickness is stated only approximately.

AGE.

The McCarthy shale is of Upper Triassic age. Some of the beds are abundantly fossiliferous, especially those near the base of the formation and in the transition zone below, and fossils can usually be found in the higher parts of the formation if search is made for them. Shells of *Pseudomonotis subcircularis* (Gabb) are so plentiful in some of the shale beds between the thin limestones that the rock can not be broken without showing them; they appear, however, to be almost the only forms represented.

A list of fossil localities follows; the determinations are by T. W. Stanton.

McCarthy Creek:
- 6314—
  - Pseudomonotis subcircularis (Gabb).

Nikolai Creek:
- 6311—
  - Two or more undetermined ammonite genera represented by fragmentary specimens.

Dan Creek:
- 6317—
  - Pseudomonotis subcircularis (Gabb).

Copper Creek (two localities):
- 6323—
  - Pseudomonotis subcircularis (Gabb).
- 6335—
  - Pseudomonotis subcircularis (Gabb).

Areas of Triassic shale are scattered along the south slope of the Wrangell Mountains as far west as the Kuskulana and probably as far as the Kotsina also, but in the earlier work in this region the Triassic shales and the black Jurassic shales were not separated because the presence of an immense thickness of Jurassic shales in this valley was not known at that time. It is now certain that a considerable part of the shale areas of Chitina Valley formerly considered to be Triassic are in reality of Jurassic age.

No Triassic shale corresponding in thickness or other characters to the McCarthy shale is known in Alaska. Other regions of Triassic sediments of similar age have been pointed out (see correlation table, pp. 26–27), but the conditions under which they were deposited were different from those in the Nizina district, and although they may be in part contemporaneous the resulting formations are distinct.

JURASSIC SYSTEM.

KENNICOTT FORMATION.

CHARACTER OF THE FORMATION.

The name Kennicott was adopted by Rohn to designate the conglomerate and sandstone succession which he found resting unconformably on the Triassic shales of McCarthy Creek and correlated on fossil evidence with the light-colored arkoses, shales, and limestones between Lachina River and Kennicott Glacier. Rohn did not recognize the black shale south of Nikolai Creek as part of his Kennicott formation, but within the district under consideration the black shale is far more important in amount than the basal conglomerate and sandstone members.

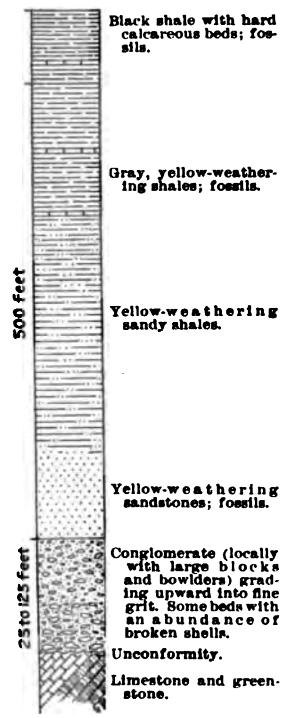

FIGURE 2.—Columnar section of the basal part of the Kennicott formation exposed on Nikolai Creek.

The Kennicott formation as the term is here used consists largely of black shale, but it includes conglomerate, grit, sandstone, and impure limestone members and is intruded by great masses of light-colored porphyritic rock. It is the youngest of the consolidated sedimentary deposits represented on the geologic map (Pl. III, in pocket) and is more widely distributed within the mapped area than any of the formations previously described. One of the characteristics of the Kennicott is its variation in appearance and composition at different localities. This statement is more applicable to its basal than to its upper part and refers to features that resulted from changing shore conditions of sedimentation. These differences will be brought out by a description of the Jurassic rocks northwest of Nizina River, where the basal part is better represented, and southeast of Nizina River, where the middle and upper parts are better represented.

The Kennicott formation where it is exposed about the head of Nikolai Creek may be subdivided into three members as follows: A basal member made up of conglomerate and sandstone; a second member consisting chiefly of light-gray, yellow-weathering shale; and an upper member of dark-gray or black shale interstratified with occasional beds of impure limestone or hard calcareous shale (fig. 2). The basal member shows notable differences in lithologic character and thickness as it is followed from one outcrop to another.

These differences, except in thickness, are dependent in large measure on the kind of rock immediately underlying the Kennicott. In nearly all places the lowest beds of the formation consist of conglomerate, but this conglomerate presents a different appearance in almost every exposure, for there is nearly every gradation between an even-grained grit whose well-worn pebbles are of uniform size and no larger than grains of wheat to a coarse agglomerate with blocks and bowlders up to 8 or 10 feet in diameter (Pl. VI, *A*). Such coarse material has probably traveled but a short distance from its source and may represent a shore-line cliff. It is not a constant feature of the basal Kennicott and its exposures are not extensive, for the very large bowlders are found in only a few localities. In many places it was noticed that most of the pebbles in the conglomerate are of the same material as the older beds on which the conglomerate rests—that is, where conglomerate overlies greenstone most of the pebbles are greenstone and where it rests on the Triassic shale most of the pebbles are shale. Limestone pebbles are not so numerous as pebbles of greenstone and shale, yet conglomerate of this formation containing a large proportion of rounded limestone fragments is found in other parts of the Chitina Valley. Some of the conglomerate contains a considerable number of diorite and porphyry pebbles, but it was not found in place in the vicinity of Nikolai Creek, where the basal conglomerate of the Kennicott is best developed within the area mapped. Nearly all of the fragments are well rounded and waterworn, and it is only in the very coarse conglomerate that angular outlines are noticeable. Even in such places the edges and corners of the blocks are usually worn away.

The filling between pebbles is finely ground material from the same source as the pebbles and is for the most part a greenish sandstone or graywacke. The average size of fragments composing the basal member of the formation decreases rapidly as distance from the base increases, until the conglomerate gives way to sandstone. In most localities about Nikolai Creek where exposures occur it is found that the upper half or three-fourths of the basal member consists of fine greenish sandstone or graywacke containing little quartz and seemingly derived largely from the Triassic shale and the greenstone. This upper part shows far less variation in character than the conglomerate, although in the base thin beds of graywacke alternate with thin beds of conglomerate. There are places where the fine conglomerate and graywacke contain considerable lime and become practically an impure limestone, but such beds are not persistent. Some of them consist in part of broken shells, yet it is difficult to find determinable fossils among them and still more difficult to secure the fossils when found, since they are in most cases partly decomposed and fragile.

A. BOWLDERS IN CONGLOMERATE AT BASE OF KENNICOTT FORMATION ON SOUTH BRANCH OF NIKOLAI CREEK.

See page 32.

B. SANDSTONE OF KENNICOTT FORMATION ON RIDGE SOUTH OF NIKOLAI MINE.

See page 33.

This lowest conglomerate-sandstone member of the Kennicott formation on Nikolai Creek has a thickness ranging from 25 to 125 feet, the greater part of which is graywacke, the remainder conglomerate or grit. In a few places the basal member appears to be entirely absent, although because of faulting and talus slopes its seeming absence may be explained in other ways. Furthermore, its persistence as a whole in many other places in spite of rapid changes in character and of variation in thickness makes it probable that if it is not seen in a particular locality the failure to find it is due to one of the causes mentioned.

The middle member of the formation on Nikolai Creek shows far less variation in character than the lower one, but it does not appear so conspicuously in other parts of the Nizina region. It consists of shale and shaly sandstone, but shale predominates. The sandy phases are more or less local, and the best exposures are on the ridge south of Nikolai mine (Pl. VI, *B*). A freshly broken surface of the shale shows a fine-grained rock of light color, but both shale and sandstone weather a bright yellow that makes them conspicuous wherever they are exposed. Both shale and sandstone break down into thin fragments under the influence of the weather, and the débris from their ledges give rise to prominent talus slopes. Occasionally fossils are found in the sandstone, and rarely a shell is seen in the shale, but fossils are not abundant and it requires some search to find any of value. The thickness of the yellow-weathering shales is as great as 500 feet in the mountain between Nikolai Creek and the East Fork of McCarthy Creek. At the head of Nikolai Creek 375 feet of yellow-weathering shale overlies the conglomerate, but some of the shale has been eroded away.

The highest member of the Kennicott in the Nikolai Creek vicinity consists of black shale, with interstratified hard, impure limestone and calcareous shale beds ranging in thickness from 1 inch to 2 feet. The hard beds form only a small proportion of the total thickness, probably less than one-tenth, but although jointed and broken they stand out in relief from the softer, crumbling black shales and form a conspicuous part of the whole. This black shale resembles closely the black shales of the Triassic. The hard beds assume a rusty-yellowish color on weathering, just as in the Triassic shales, and there seems to be no way, except by their stratigraphic position and their fossils, to distinguish them from the older shales. Fossils are fairly plentiful in some beds of this member, especially those in the hard beds, and are in a better state of preservation than those found lower in the formation.

From 125 to 150 feet of these shales are exposed north of Nikolai Creek, but the figures take no account of what has been removed by erosion or what has been caught up into the intruded porphyry.

Locally erosion has destroyed the upper member, leaving the basal and middle members. In some localities both the middle and the upper members have been removed, and without doubt the Kennicott was once present in large areas where no trace of it is now found.

The section of the Kennicott formation exposed on Dan Creek is many times thicker than the section that has been described. The Nikolai section represents a phase of the basal Kennicott that is thought to correspond more fully with the Kennicott observed west of Kennicott Glacier and still farther west in the Chitina Valley than does the Dan Creek section. An excellent exposure of the base of the Kennicott formation was found on Eagle Creek, in the Copper Creek valley. All the upper part of the long ridge separating Eagle Creek from Copper Creek is made up of lower Kennicott beds. They rest on the edges of thin limestone and shale beds that belong to the transition zone between Chitistone limestone and McCarthy shale. The limestone and shale beds have a dip about 20° greater than the overlying Kennicott, and the unconformity is shown in diagrammatic clearness. The basal beds of the Kennicott at this place consist of from 150 to 200 feet of fine conglomerate or grit overlain by sandstone. Black shale overlies the sandstone and forms the top of the ridge extending southeast to the main mountain mass. This basal grit was traced northwest in Copper Creek valley to the vicinity of the limestone area north of Idaho Gulch. It may be regarded as a constant feature of the Kennicott in the Nizina district. In most places it is somewhat fossiliferous. Pyramid Peak, at the head of Copper Creek, appears to be made up entirely of rocks belonging to the Kennicott formation. The lower part is black shale, but the top shows bedding lines that are thought to represent sandstones and impure limestones. Sandy shales and hard sandstones are interstratified with the black shales on Rex Creek, and the tops of the mountains between Rex Creek and White Creek contain a large amount of gray sandstone and impure limestone. Beds of brown-weathering nodular limestone in the shales high up on the slopes of these mountains contain ammonite shells 15 or 18 inches across. These mountains appear to be at the axis of a broad shallow syncline and give good sections of the formation.

A feature of geologic interest is presented by the sandstone dikes that cut the black shales east of Rex Creek. These dikes range in thickness from a fraction of an inch to 5 or 6 inches and cut the shales just as an igneous dike would. They are composed of angular fragments of quartz, feldspar, biotite, calcite, and pyrite mingled with fragments of shale. They are composed of the same material as some of the associated sandstone beds and are numerous in places.

Bedding in the black shales of Blei Gulch, on the south side of Chititu Creek, is shown by lines of small limestone concretions and thin discontinuous calcareous beds. More than 4,500 feet of black shale dipping low to the southwest is exposed in Blei Gulch. Young Creek, south of Chititu Creek, flows in a shallow canyon whose walls are composed of black shale of the Kennicott formation. This shale forms the lower slopes of the ridge south of Young Creek, and it is probable that Kennicott sediments make up most of the ridge. The ridge was not examined in detail owing to lack of time, but a section up the first southern tributary of Young Creek east of Calamity Gulch shows rocks of the Kennicott formation. The section extends up the east branch of this creek. For a distance of nearly three-fourths of a mile from its mouth the creek flows over black shales with occasional limestone beds, all dipping southwest at angles of 30° or less. Thence for nearly a fourth of a mile are rocks that have been crumpled and much faulted. They consist of shales with interbedded calcareous shales and limestone, from which fossils were collected. In many places the strata of this disturbed zone stand on edge, and it is evident that displacements of importance have taken place. A peculiar feature of this locality is seen in the limestone nodules, which occur in beds and reach diameters of 2 or 3 feet. They consist of bluish-gray limestone and show parallel bedding lines crossing them. They were seen at a number of places on Young Creek. South of this faulted zone the creek flows for another three-fourths of a mile over black shales and thin gray and brown sandstones. The shale predominates but the sandstones form an important part of the whole. The dip of these shales and sandstones is steeper than is usual in the Kennicott formation of the Nizina district, ranging from 30° to 50°. A massive conglomerate succeeds the shale and limestone on the south at a point 1,500 feet above Young Creek. The conglomerate is several hundred feet thick and is made up of well-rounded pebbles loosely cemented together, many of which are 5 or 6 inches in diameter. It appears to have been deposited conformably on the underlying shale-sandstone beds, but there is reason to believe that movement has taken place along the contact at this locality. No proof was secured to show that this great conglomerate does not mark an unconformity in the Kennicott formation or between the Kennicott and a succeeding formation, but the relation appears to be one of conformity in other places west of this creek where the contact was examined. Flat-topped or mesa-like hills composed of conglomerate beds dipping low to the south are scattered along the top of this ridge both to the east and to the west of this section. According to Schrader's field notes of 1900, the conglomerate on the west end of the ridge south of Young Creek is interstratified with a few beds of arkose sandstone and probably does not exceed 500 feet in thickness. It contains granite bowlders up to 9 inches in diameter, dark limestone, flint, quartz, gray slate and grit, and green gneissic rock, but

Schrader did not find any pebbles of Nikolai greenstone. The arkose or sandstone underlying the conglomerate was measured by Schrader in a very favorable section, where the dip was low to the south-southeast, and was found to be between 2,000 and 2,500 feet in thickness.

There is no reason to doubt that this succession of shales, limestones, sandstones, and conglomerate found in the ridge south of Young Creek corresponds to the bedded rocks seen in the high mountains at the head of Copper, Rex, and White creeks. It therefore represents the upper part of the Kennicott formation as it is known at present.

The unconformable relation of the Kennicott formation to the older sedimentary rocks and the Nikolai greenstone is plainly seen in both the localities whose sections have been described and is shown in the view (Pl. VII, *A* and *B*) taken at the head of Nikolai Creek. Kennicott sediments there rest on the upturned and truncated beds of the Nikolai greenstone, the Chitistone limestone, and the McCarthy shale. The dip of the younger beds is low in most places, ranging from 10° to 20° W. or SW. On the other hand, the dip of the underlying sediments and the lava flows (Nikolai greenstone) are considerably greater and in a different direction, averaging about 30° or 35° NE.

One feature of the Jurassic sediments that is more noticeable on White and Young creeks than in other parts of the district is the rapidity with which they break down under the action of weathering. Such topographic forms as Blei Gulch and the gulches tributary to Young Creek are due to this cause. Blei Gulch in particular shows how readily the shales are attacked and how little they are able to resist the attacks as compared with the greenstone and limestone. The soft shale débris accumulates faster than the water can carry it away and the mouth of the gulch is choked with it.

The Kennicott was deposited on an old submerged land surface. In a broad way this surface on which the Kennicott formation of Nikolai Creek lies was flat, but it is readily seen on examining the contact that there were minor irregularities in it such as are present in any level country. The conglomerate and graywacke beds of the basal Kennicott sag down into hollows of the underlying surface, and at one locality pebbles and sand were seen filling old cracks in the Chitistone limestone.

DISTRIBUTION.

The Kennicott formation occupies probably three-fourths of the total area represented on the geologic map (Pl. III, in pocket), for if a line be drawn from the mouth of National Creek to Pyramid Peak practically all of the consolidated deposits south of it are Kennicott. It forms the high angular mountains between Dan and Chititu

A.

B.

UNCONFORMITY BETWEEN TRIASSIC AND JURASSIC FORMATIONS AT HEAD OF NIKOLAI CREEK.

a, Sandstone and shale of Kennicott formation; *b*, Chitistone limestone; *c*, Nikolai greenstone. The two views placed side by side would form a panorama. See page 36.

creeks and makes up the principal part of Porphyry and Sourdough peaks, although its presence is so obscured by porphyry intrusions in these two last-mentioned mountains that its amount is apt to be underestimated. It doubtless underlies also the gravel deposits of the lowland south of Nizina River.

Without question Jurassic sediments are far more widespread in Chititu Valley than was suspected before the field work of 1909 was undertaken. They extend eastward beyond the Nizina district into the upper valley of the Chitina and westward along the flanks of the Wrangell Mountains, where it is certain that they have not been fully differentiated from the Triassic shales, just as was true in the Nizina district. The separation of Jurassic from Triassic shales will require more detailed field work than has yet been given them.

FIGURE 3.—Generalized columnar section of the Jurassic sediments in the Nizina district.

THICKNESS.

No such favorable section was found for measuring the thickness of the Kennicott formation as that furnished by the walls of Nizina River for measuring the Chitistone limestone, and the figures given are secured from a study of a number of sections at different localities (fig. 3). The total thickness given should be regarded as having only approximate accuracy.

The coarse fragmental beds, including conglomerate and grit at the base of the Kennicott, range in thickness from 25 to 150 or 200 feet. An intermediate figure of 100 to 150 feet is believed to represent a fair estimate for the thickness of these beds throughout the district. It seems proper to include the yellow-weathering shales and sandstones of Nikolai Creek with the black shales, since they are a local feature and contemporaneous in time of deposition with the lower part of the black shale south of Nizina River. On this basis the black shale member at the heads of Copper and Rex creeks has a minimum thickness of not less than 4,500 feet, yet the black shales of Williams Peak south of Dan Creek suggest a considerably greater thickness, possibly as much as 6,000 feet. This measurement includes all beds from the top of the conglomerate and grit to the beginning of the interbedded shale-sandstone succession that forms the tops of the high mountains at the heads of Copper and Rex creeks and the upper part of the ridge south of Dan Creek. The shale-sandstone member has a thickness of about 2,500 feet. If, now, 500 feet, representing the heavy conglomerate of Young Creek, be added to the measurements already given, a minimum thickness of over 7,500 feet is obtained for the Kennicott formation in the Nizina district.

AGE AND CORRELATION.

Fossils have been collected from all parts of the Kennicott formation, but unfortunately the stratigraphic range of the forms is so great that they do not fix its age definitely. It appears most probable that the Kennicott formation was laid down in Upper Jurassic time, but there is a possibility of its being Lower Cretaceous. The probability of its Jurassic age rests in considerable measure on the presence of a species of *Aucella* collected first by Rohn and later by Schrader and Spencer and identified by T. W. Stanton. Schrader and Spencer collected fossils at other localities as well as in the Nizina district, and on the evidence of these fossils the formation was referred to "the doubtful series lying at the top of the Jurassic or at the base of the Cretaceous."[a]

The list of fossils follows.

Inoceramus eximius Eichwald?	Aucella pallasi Keyserling?
Belemnites sp.	Lytoceras sp.
Halobia occidentalis Whiteaves?	Hoplites sp.
Rhynchonella sp.	Olcostephanus? sp.
Pecten sp.	Gryphæa sp.
Avicula sp.	Sagenopteris sp.

Concerning *Inoceramus eximius* Dr. Stanton says:[a]

This form is represented by a single specimen collected on Chitty Creek. It may be distinct from Eichwald's species originally described from Turkusitun Bay, in Cook Inlet, and referred by him to the Neocomian. Eichwald described three other species—*I. ambiguus*, *I. porrectus*, and *I. lucifer*—all belonging to one section of *Inoceramus* from the same horizon in Alaska. The present shell does not agree perfectly with any of the figures, but it is most nearly like *I. eximius* and probably comes from the same formation. Similar forms occur both in the Jurassic and in the Cretaceous, but the evidence of the other fossils from this part of Alaska favors the reference of the Kennicott formation to the Jurassic.

[a] Schrader, F. C., and Spencer, A. C., The geology and mineral resources of a portion of the Copper River district, Alaska: Special publication of the U. S. Geol. Survey, 1901, p. 50.

Of the form referred with a question to *Halobia occidentalis* Dr. Stanton says:

The specimens agree fairly well in sculpture and general appearance with some of the figures of Whiteaves's species from the Liard River and may be identical with it. They are, however, somewhat suggestive of *Hinnites linænsis*, from the Jurassic(?) of Siberia.

Sagenopteris is a genus which occurs both in the Jurassic and in the Cretaceous, but the species is thought by Prof. Ward, to whom it was shown, to be near a species occurring in the Jurassic of the Pacific coast.

Concerning the general relations of the fossils from the Kennicott formation Dr. Stanton observes:

These fossils are all either Upper Jurassic or Cretaceous, with a suggestion of a somewhat younger age for a few localities. In the present state of knowledge and with these small collections it is not practicable to determine whether they represent one horizon or several. In my opinion, they probably all belong to the Upper Jurassic, though subsequent work may show the contrary. The question is connected with the still unsolved problem of the exact boundary between the Jurassic and the Cretaceous in the *Aucella*-bearing beds of Russia, Siberia, and the Pacific coast region of North America. The *Aucella* occurring in the Copper River district appears to be referable to a Russian Jurassic species, but it is also quite similar to the Cretaceous form in the lower Knoxville beds of California. The few other forms are mostly undescribed species of types that occur both in the Jurassic and in the Lower Cretaceous.

A single fossil collected on Chititu Creek in 1907 was referred to Dr. Stanton and described by him thus:

Chititu Creek:
- 4811; No. 26—
  - Perisphinctes, sp. This ammonite is not a typical Perisphinctes, but it is probably of Jurassic age, certainly not older than Jurassic.

The much larger collection made in 1909 was also referred to Dr. Stanton, who says of them: "The fossils from the Kennicott indicate that one fauna ranges throughout the formation and that its age is most probably Jurassic, though the types represented in the collection are not as definite as could be wished for determining between Jurassic and Cretaceous. The entire absence of *Aucella* is noteworthy in view of the fact that that genus has previously been reported from the formation." The list of fossils arranged by localities and with the catalogue numbers of the National Museum follows.

McCarthy Creek:
- 6301—
  - Inoceramus sp.
- 6313—
  - Lytoceras sp.
  - Phylloceras sp.
    - Base of Kennicott.

Nikolai Creek:
- 6302—
  - Inoceramus sp.
    - Base of Kennicott.
- 6304—
  - Rhynchonella sp.
  - Pecten sp.
    - Base of Kennicott.
- 6305—
  - Rhynchonella sp.
  - Terebratella? sp.
  - Exogyra sp.
  - Pecten sp.
    - Collected near 6304.
- 6307—
  - Phylloceras sp.
- 6308—
  - Inoceramus sp.
    - Lower part of Kennicott formation.
- 6309—
  - Rhynchonella sp.
  - Inoceramus sp.
- 6310—
  - Rhynchonella sp.
  - Terebratella? sp.
    - Base of Kennicott formation.
- 6331—
  - Rhynchonella sp.
  - Terebratella? sp.
  - Ostrea sp.
    - Near base of Kennicott formation.

Sourdough Hill:
- 6315—
  - Inoceramus sp.

Dan Creek:
- 6316—
  - Inoceramus sp.
- 6318—
  - Bowlder in conglomerate of Kennicott formation.
  - Halobia superba Mojsisovics?

Copper Creek:
- 6322—
  - Rhynchonella sp.
  - Undetermined small Pelecypoda.
  - Natica sp.
  - Undetermined ammonite.
    - Base of Kennicott formation.

Texas Creek:
- 6334—
  - Phylloceras? sp.

Rex Creek:
- 6324—
  - Irregular echinoid, crushed specimens.
  - Pecten sp.

Rex Creek—Continued.
6324—Continued.
Terebratula sp.
Ostrea sp.
Anomia sp.
Inoceramus sp.
Nucula sp.
Arca sp.
Undetermined Gastropoda.
Phylloceras sp.
Shark's teeth.
Well up in the Kennicott formation.
6425—
Serpula sp.
Ostrea sp.
Pecten sp.
Arca sp.
Cyprina? sp.
Corbula sp.
Aporrhais sp.
Chemnitzia? sp.
Crioceras? sp.
6426—
Fragment of large ammonite.
Higher in the formation than 6324.
6336—
Undetermined fragmentary ammonite.
White Creek:
6327—
Ostrea sp.
Upper part of Kennicott formation.
6328—
Fragment of large ammonite.
High up in the Kennicott.
Young Creek:
6329—
Cyprina? sp. (fragment).

The absence of *Aucella* from the collections of 1909 raises a question concerning the Kennicott that can not be answered with the data at hand. If, as seems probable, its absence is due merely to the failure to find it, there is no reason to suspect any difference in age of the Kennicott sediments east and west of Kennicott Glacier. If, on the other hand, it does not occur east of Kennicott Glacier, the possibility that the basal Kennicott beds west of the glacier are older or that the sediments of the two localities are not correctly correlated is apparent.

It will be seen from the table of correlation (pp. 26–27) that Jurassic sediments are widespread in Alaska. They are found along the Pacific coast side from southeastern Alaska to the peninsula, and again on the Arctic slope, but are not known in the Yukon Basin.

Attention is directed more particularly to the Nabesna-White district, the Matanuska and Talkeetna district, and the region of Cook Inlet and the Alaska Peninsula.

The Nutzotin Mountains, northeast of the Wrangell group, consist of a great thickness of banded slates, graywackes, and conglomerates associated with limestone and sandstone beds in minor amount. Upper Jurassic fossils were collected from these beds, but the beds are very imperfectly known, and it is highly probable that they include also Triassic or even older beds. They are exposed in the canyon of Chisana River for a distance of 18 miles, and, although they are much folded, it is evident that their thickness is great.

Lower Middle Jurassic and middle and upper Middle Jurassic sediments occupy extensive areas in the region of Matanuska and Talkeetna rivers.[a] The lower Middle Jurassic rocks have a thickness of 2,000 feet, more or less, and consist of shales, sandstone, and conglomerate, with coal, associated with andesitic greenstone, tuffs, agglomerates and breccias, rhyolites, dacites, and tuffs. On these was deposited unconformably more than 2,000 feet of middle and upper Middle Jurassic shales, sandstones, conglomerates, tuff, and arkose, with coal. More than 1,000 feet of this is conglomerate.

The Jurassic rocks of Cook Inlet and the Alaska Peninsula were studied by Stanton and Martin in 1904[b] and again by Martin in the region of Iliamna Bay in 1909. They include rocks of Lower, Middle, and Upper Jurassic age. The deposits referred to the Lower Jurassic consist chiefly of water-laid tuffs, and are found at Seldovia, on the east side of Cook Inlet, and probably on the west side also. The Middle Jurassic sediments, called by Stanton and Martin the Enochkin formation, include shale and sandstone, with a few thin beds of limestone and conglomerate, and reach a thickness of 2,415 feet on the shore of Chinitna Bay. This section does not include the lower part of the Enochkin formation, yet the thickness given represents what is probably the average thickness of the formation. Upper Jurassic sediments succeeded the Enochkin formation. They were first described by Spurr[c] and received their formation name from Naknek Lake. The Naknek formation includes shale, sandstone, conglomerate, arkose, tuff, and andesite. A thickness of 5,137 feet of rocks belonging to this formation was measured by Stanton and Martin on the north shore of Chinitna Bay. Lower, Middle, and Upper Jurassic deposits thus reach a thickness of 7,500 to 8,500 feet in this region.

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[a] Paige, Sidney, and Knopf, Adolph, Geologic reconnaissance in the Matanuska and Talkeetna basins, Alaska: Bull. U. S. Geol. Survey No. 327, 1907, pp. 16 and following.

[b] Stanton, T. W., and Martin, G. C., Mesozoic section on Cook Inlet and Alaska Peninsula: Bull. Geol. Soc. America, vol. 16, 1905, pp. 391–410.

[c] Spurr, J. E., A reconnaissance of southwestern Alaska: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 7, 1900, pp. 169–171.

It has been seen from the brief description given that the Jurassic section is more nearly complete as it is traced westward from the Chitina Valley. The evidence is too incomplete to draw definite conclusions, but it appears that about the lower part of Cook Inlet Lower, Middle, and Upper Jurassic sediments are present, that in the Talkeetna and Matanuska district the Lower Jurassic is lacking, and that in the Chitina Valley both Lower and Middle Jurassic are absent. A possible explanation of this condition is that the invasion of the Jurassic sea was from the west and that the successive dropping out of the lower members from the stratigraphic section is evidence of progress in the eastward advance. This explanation, however, is not the only one, for the lower divisions of the Jurassic may yet be found in the Chitina Valley, or they may have been removed by erosion if ever present. In this connection, also, attention may once more be drawn to the fact that the known Jurassic sediments of Alaska are found on its Arctic and Pacific sides. They have not been discovered in the Yukon Basin.

QUATERNARY SYSTEM.

PREGLACIAL CONDITIONS.

So far as known, the region under discussion was elevated above sea level at the end of Eocene time and has ever since remained a land area. During and after the cessation of the mountain-building processes which raised the land to its present elevation stream erosion was active and well-developed drainage systems were formed, the area and distribution of which were perhaps very much as they are to-day. The topography of the land surface and the arrangement of the smaller drainage lines must, however, have been greatly different from those existing at present. The relief was developed by stream erosion, and in a region of such great relief the streams must have occupied narrow V-shaped valleys, with the spurs between the lateral tributary valleys overlapping in such a way as to give the streams a somewhat sinuous course around the points of the interlocking spurs. Furthermore, there must have been a heavy covering of residual soil and rock waste mantling the ridges. Stream erosion was the controlling factor in the development of the topography up to the beginning of Pleistocene time.

PLEISTOCENE ("GLACIAL") EPOCH.

CHARACTER AND EXTENT OF GLACIATION.

A change in climatic conditions inaugurated the Pleistocene epoch, with a lowering of the temperature or an increase in precipitation, or both. Ice began to form in the heads of the more favorably situated valleys, and with the gradual accumulation of ice glacial movement was started. The small glaciers which formed in the heads of a great number of separate valleys moved gradually downward to meet and merge in the main valleys. Three primary glaciers existed within the limits of this district, two of them (in the Kennicott and the Nizina valleys) moving southward and one (in the Chitina Valley) moving westward.

It is possible that the Pleistocene epoch has been represented in these mountains by more than one great ice advance, with interglacial epochs in which the ice diminished greatly in area and may even have disappeared in large part. No direct evidence has been obtained that this was the case in Alaska, as the last great ice advance obliterated all evidence of previous advances. In other mountain regions in the United States and Canada a succession of ice advances has been established, and somewhat similar conditions have probably prevailed in Alaska. The effects of earlier ice invasions may have had an important influence upon the erosion of the deep glacial valleys of this region, but the immediate effects now remaining, such as the distribution of moraines and glacial gravels, are to be ascribed to the action of the last great glaciers which filled these valleys.

As already stated, the dissection of the area in preglacial time had been accomplished by normal stream erosion. Great quantities of soil and rock waste were ready at hand for the glaciers, and these materials were incorporated into the advancing ice tongues and served as abrasives for the glaciers to use in the further grinding out of their beds. As they advanced down their valleys they encountered opposition from the spurs which projected into the valleys, and as the ice was able to override these spurs it was upon them that its erosion was most effective. This selective erosion of projecting bodies of rock was carried on continuously, and the resultant is the broad, U-shaped, troughlike gorge which is recognized as the evidence of severe glacial erosion. Erosion in the valleys, however, was not confined to the removal of overlapping spurs. The rock fragments held in the bottoms of the glaciers and pressed down upon their floors by the weight of several thousand feet of ice formed admirably adapted tools for grinding down the floors and rasping away the walls. It is impossible to estimate with any degree of accuracy the amount of glacial deepening which the trunk valleys have undergone. The difference in elevation between the mouth of a hanging tributary valley and the floor of the main valley below may be considered to offer a fair basis for estimating this deepening, and in many places this discordance is from 1,000 to 1,500 feet. Some such figure may well represent the depth to which glacial scour has lowered the larger valleys.

At the time of the last great period of glaciation the Nizina region was invaded by an ice flood which covered it to such an extent that the surface relief within the area was not more than 4,500 feet as compared with more than 7,700 feet at the present time. Only the high ridges between the principal drainage lines projected above the surface of the ice streams. The land areas were restricted to narrow, angular masses of irregular outline cut into on all sides by the smaller glaciers, which headed back toward the crests of the divides. An attempt has been made (Pl. III, in pocket) to outline the land areas which projected above the glaciers. This outline can not be considered as exact, but it must represent with a fair degree of accuracy the areas which stood up above the ice surface. Of the total area of the Nizina special map (300 square miles) only about 18 square miles remained unglaciated.

The depth at which the ice stood in the different valleys can in favorable places be determined rather closely by the present distribution of glacial moraines and erratic bowlders and by the shapes of the eroded valley walls. Certain mountains, we know, must have stood above the glaciers, because of the angular, rugged character of their summits, which fail to show the effects of the abrasive action of the ice. Other mountains, we know, must have been overridden by the ice, because of their smoothed and rounded outlines and because of the occurrence on their tops of glacial bowlders of rocks which occur in place nowhere in the vicinity of their present resting places. From such evidence it is found that in Nizina Valley, at Sourdough cabins, the top of the glacier must have stood more than 3,000 feet above the present river flat.

CHITINA GLACIER.

The Chitina Valley, which extends from the head of Chitina River near the international boundary in a west-northwest direction to the Copper River basin, is the channel which drained all the ice fields from the south side of the Wrangell Mountains as well as those from the north slope of the Chugach Range. Although only one edge of the Chitina Glacier lay within the area of the Nizina special map, it may not be out of place to give here some idea of the size of this ice tongue as a whole. At its maximum it was about 120 miles long in its own valley, and it joined the Copper River Glacier, the length of which below the junction of the Chitina is not known, although it must have been considerable. The ice field had a width for portions of its course of 20 miles and averaged about 12 miles, so that its total area was not far from 1,500 square miles, exclusive of all tributary glaciers. South of this area it was certainly close to 4,000 feet in thickness and may have been much thicker. On account of its great thickness the ice surmounted the divide between Chitina River and Young Creek and pushed to the northwest, covering the ridge between Young and Chititu creeks, so that the northern boundary of this great ice field was here the high mountain ridge north of White Creek. That it completely covered the high divides south of this ridge is evident not only from the smoothed and subdued slopes of their summits but from the presence on them of scattered bowlders of rocks strange to this immediate vicinity. In Chititu and White creeks there are numerous bowlders of greenstone, although none occurs in place within this drainage basin. Their presence here as well as that of the native copper and silver found in the placer gravels is doubtless due to the transportation of glacial ice, the bowlders in White Gulch having been brought from the east by the Chitina Glacier, and the bowlders in Rex and Chititu creeks either by the same ice tongue or from the north by the Nizina Glacier. Much of the native copper and greenstone of Young Creek was brought in by the Chitina Glacier, although there may be greenstone in place at the head of this creek. There is still a large glacier at the head of Chitina Valley, though little is known of its length or appearance.

NIZINA GLACIER.

The head of the Nizina Basin is still occupied by a great glacier, which now terminates about 11 miles above the mouth of Chitistone River. The valley below, however, shows strongly the erosion of the former glacier which moved down it. Tributary ice tongues entered the valley from both sides north of the area here considered, but within it the large branches all came in from the east. The northernmost and by far the most important branch came down the Chitistone Valley. This stream drains a basin which extends northeast to Skolai Pass and east into a range of high glaciated mountains. That the valley was the outlet for a vigorous glacier is evident from the steep-walled trough through which the stream now flows. The valley floor near the mouth of the canyon is only three-eighths mile wide, but the ice in it once reached a depth of at least 3,500 feet and was able to keep its trough cut down to grade with the floor of the Nizina Valley. Toward the lower end of the Chitistone Valley the tops of the mountains on both the north and the south sides are flat and mesa-like, and, although the valley glacier did not extend up to these mesas, they were occupied by glaciers which must have extended to their edges and cascaded down upon the valley glacier below, so that only a portion of the steep cliffs at the upper limit of the valley walls were free from ice.

Five miles south of the Chitistone a tributary ice tongue fed into the Nizina from Dan Creek. This lobe drained the ice from a much smaller basin than the Chitistone and excavated its valley much less severely. In it the depth of the ice was great, but this was due more to the damming back by the great glacier in the Nizina Valley than to its own supply, and the movement must have been comparatively sluggish. Besides receiving ice from a large number of cirques, some of which are still occupied by small glaciers, this lobe was fed by the ice sheet on the mesa to the north. This ice sheet still exists and covers most of the flat uplands, but now sends ice over its edge at only a few points.

The main valleys of Chititu and Young creeks were invaded by ice from the Chitina Glacier, which spread over the intervening ridges and made a continuous ice sheet from Chititu Creek to the south side of the Chitina Valley. Rex Creek, however, was separated by a high ridge from the Chitina ice and sent down a tributary tongue to join the great ice flood at the junction of the Nizina and Chitina glaciers.

KENNICOTT GLACIER.

The Kennicott Basin is occupied in its upper portion by a glacier which extends within 5 miles of the mouth of Kennicott River. The area of the Nizina special map includes about 10 square miles of the eastern edge of this ice tongue. A line drawn from Kennicott to the point of junction of the two principal branches of the glacier separates the white ice of the east fork from the moraine-covered ice of the lower portion. The west fork, which is the larger, heading on the flanks of Mount Blackburne, shows a banded, ribbon-like surface of lines of white ice alternating with long surface moraines. Below the junction of the two branches the white bands disappear and the glacier presents a chaotic surface of sharp hills and deep, wide-mouthed crevasses, all more or less thickly covered with débris. Part of the drainage from the melting ice runs off as streams, which flank the lower portion of the glacier on either side, but much the greater part of the water emerges from what is known as the "pothole," at the lower end of the glacier. The pothole is the mouth of a subglacial channel, and Kennicott River boils out of this opening as a gigantic spring. In winter the pothole has been known to freeze up, damming back the water until sufficient hydraulic pressure has been developed to break away the ice, when a torrent of water rushes down Kennicott and Nizina rivers, sometimes flooding the ice all the way to Copper River.

The severity of the earlier glaciation in the Kennicott Valley is comparable to that of the Nizina. The ice extended southward to join the great Chitina Glacier, which had already been swelled by the ice from the Nizina. The surface of the glacier at Kennicott then stood about 3,000 feet higher than it does to-day, and the severity of its erosion is shown by the straight lines of the contours along the mountain sides and by the complete absence of projecting spurs.

The Kennicott Glacier had within this area one important tributary, which occupied the valley of McCarthy Creek. Its course, like that of the Kennicott and Nizina glaciers, was from north to south, and its erosion was sufficient to reduce its valley to a straight, U-shaped trough. Within the area of this map all the important tributaries to McCarthy Creek Glacier came in from the east, especially from the valleys of Nikolai Creek and East Fork. At one time the ice surface stood 1,000 feet above the divide at the head of South Fork of Nikolai Creek, and it is probable that some of the ice from the Nizina Glacier moved westward over this col and then down the McCarthy Creek valley. Below Sourdough Peak the Kennicott, McCarthy, and Nizina glaciers all joined the great Chitina ice stream and moved northwestward down the Chitina Valley.

In the preceding paragraphs the attempt has been made to describe the glaciers of the region at the time of their greatest development. The individual ice lobes and their interrelations would have been different at lesser stages of development. The arrows shown on the map (Pl. III, in pocket) represent the directions of ice movement in the different parts of the area.

RETREAT OF THE ICE.

In the earlier stages of glaciation of the region the ice no doubt built up lateral and terminal moraines, but further advances destroyed or obliterated all traces of the earlier deposits. It is only those deposits that were laid down at the time of or subsequent to the maximum advance of the ice that have been preserved, and in many places even this material has been removed by stream cutting or been covered with stream deposits. There are left only a few areas of distinctive terminal moraine, having the characteristic hummock and kettle topography. Some such moraine still exists west of the lower portion of Young Creek, and some east of lower Chititu Creek, with occasional more recent patches like that on Texas Creek near the head of Copper Creek. These areas often contain lakes which occupy undrained depressions in the glacial deposits. The absence of strong moraines in most of the valleys is due, in part at least, to the vigorous cutting of the streams, which have long ago removed them. The Kennicott Glacier, which terminates near the mouth of McCarthy Creek, has remarkably little moraine around its edges, and although the surface of the lower portion of the glacier is covered with detritus the streams have removed this as fast as it has been dropped by the ice and in many places are cutting into the glacier itself.

Glacial till or bowlder clay is rather widely distributed in this area along the lower slopes of the valley walls. Its surface is generally covered by a heavy growth of mosses and timber, but fresh exposures can be seen at many places along the banks of streams. It consists of a rather dense blue clay in which are embedded bowlders, pebbles, and angular fragments of many different kinds of rock, and it is characterized by unassorted materials and lack of stratification.

BENCH GRAVELS.

As climatic conditions became less favorable for glaciation and the ice diminished from its greatest thickness the glaciers in many of the smaller drainage lines tributary to the larger trunk valleys shrank until they no longer joined the main ice lobes below. Thus the lower part of McCarthy and Dan creek valleys were free from ice while their mouths were blockaded by the Kennicott and the Nizina glaciers. In like manner the ice in the Chitina Valley had shrunk so that it was no longer able to override the ridges on either side of Young Creek, and Chititu and Young creeks had lost their ice while the Nizina Glacier still stood high in the valley to the northwest. As a result the drainage in many valleys was impeded by the ice dams across their mouths, and the streams began to fill in their basins with gravel deposits. It may be that temporary lakes were sometimes formed behind the ice barriers, but the character of the gravel deposited indicates that if such lakes existed they must have been of short duration.

Gravel fillings behind glacier dams in many places reached a great thickness. In Young Creek valley, above the portion where the creek flows north, the gravels are in places more than 500 feet thick near the center of the valley and thin out at the sides. The upper limit of the gravels is difficult to determine on account of the thick coating of moss with which the surface is covered, but it probably lies for the most part between the elevations of 3,250 and 3,500 feet. In Chititu Creek, at the mouth of Rex Creek, a similar thickness of gravels was reached. At the point where Dan Creek emerges from the mountains a great bench more than 700 feet high shows that the stream floor was graded up to that level when the Nizina Glacier still filled the valley below. In the McCarthy Creek valley a broad area was filled with gravels deposited under similar conditions. An advance by the Kennicott Glacier of only 2 or 3 miles would be sufficient to cause McCarthy Creek to begin again the grading up of its valley with gravels like those of which the gravel benches are composed.

In all of the valleys mentioned the alluvial filling was due to the presence of an ice barrier which retarded the drainage and caused the streams to build rapidly. As the great glaciers retreated and their thickness decreased the barriers to the tributary streams were lowered and they began to cut into the gravel filling which they had laid down. They did not, however, remove the filling from the whole width of the valleys, but intrenched themselves in this filling and developed deep gorges with gravel banks. Throughout much of the upper part of Young Creek and in parts of Chititu, Dan, and McCarthy creeks the streams have now cut completely through the gravels and into the rock below, leaving the valley filling as terraces or benches on either side of the streams. In Young Creek valley, especially, many lateral tributaries have also cut through the gravels, which now form interrupted benches along the slopes to the north and south of the stream.

PRESENT STREAM GRAVELS.

The larger glacier-fed streams of the area are in sharp contrast, both in appearance of water and in character of valley deposits, with the streams which do not head in active glaciers. The streams which are supplied only by melting snow and by the ordinary run-off are for the most part clear, and they are gradually cutting their valleys deeper. The glacier-fed streams, on the contrary, are supplied with great quantities of detritus by the glaciers, and during the warm season they are turbulent and heavily loaded, so that they are constantly building up their valleys with gravels and silts brought down from above. The Nizina Valley is a conspicuous example of this building process. The present flood plain ranges in width from one-fourth mile at the extreme western edge of the area mapped to more than 2 miles at its widest points. The flat is composed of gravel bars, for the most part bare of vegetation though some of the higher portions are timbered. The proportion of the flat that is covered by water at any one time not only varies greatly with the seasons, but often there is a great daily range as well. Since the water supply is largely furnished by the melting of the glaciers and of the snow on the mountains, the streams are highest in July, and in periods of high water a large part of the flat is covered. During the late fall and winter the rivers dwindle until but little water flows beneath the ice. The daily range, too, is largely controlled by the temperature, the streams being lowest in the early morning but on bright, sunny days increasing in volume until the late afternoon, when the flow is many times as large as it was early in the day.

All of these variations in volume are important factors in the transportation and deposition of débris. In high stages the streams are most turbulent and great quantities of gravel and silt are carried by them. In low stages the water becomes clearer and but little material is moved. As a result of their overloaded condition during the summer, the streams, which flow in some places as single streams and in others as intricate networks of channels, are constantly shifting their courses over the flood plains, building up bars in some places while cutting them away in others. In the Nizina Valley below Young Creek the present tendency of the river is to lower its bed, owing to the increased gradient given by the cutting down of Nizina Canyon below. Above Young Creek the valley floor is being built up, the building proceeding most rapidly at the mouths of the tributary streams. Chititu Creek has a large low-grade fan below its canyon, but the edge of this fan has reached the Nizina flood plain at only one point. Dan Creek also has a low fan extending out to the Nizina bars. The largest deposit from a tributary stream is that at the mouth of Chitistone River. Here a wide fan of low slope has crowded Nizina River over against the rock cliffs on its west valley wall, where in places all the talus slopes have been removed and the flood plain extends flush up against the limestone cliffs. This fan has also been effective in retarding the current of Nizina River above it and in aiding deposition there.

McCarthy Creek flows for the lower 10 miles of its course through a more or less narrow valley intrenched into the gravel deposits and into its rock bed, but above this portion the valley floor is broad and gravel filled.

POSTGLACIAL EROSION.

The agencies of rock weathering and erosion are very active in this region of great daily ranges in temperature, high altitudes, and steep slopes, so that the amount of rock material which has been removed since the retreat of the great glaciers has been large. The timber line throughout the district lies at about 4,000 feet or lower, although willow and alder bushes flourish above this and are sometimes found up to an elevation of 5,000 feet. Above 5,000 feet vegetation is sparse and most of the surface is bare and exposed to the agencies of weathering. Large talus slopes occur below all steep cliffs. The greenstone is perhaps most resistant of all rocks in this vicinity, and the talus accumulations below greenstone outcrops are small as compared with those below similar cliffs of the more easily weathered rocks. The Chitistone limestone follows the greenstone in its ability to resist weathering, although, as is to be expected, there are often large talus slopes below the enormous cliffs which this limestone offers. The porphyry weathers much more rapidly than either greenstone or limestone, and the sides of those mountains which are composed of this rock are almost invariably buried beneath great talus aprons. In the steep-sided porphyry mountain between the Kennicott and McCarthy Creek the talus is so abundant that few outcrops occur below an elevation of 5,000 feet and only the upper craggy portion of the mountain is free from talus. Both Triassic and Jurassic shales weather readily, the latter with the greater ease on account of its freedom from hard beds of limestone. A great amount of postglacial stream cutting has been done in the Triassic shales between McCarthy Creek and the Nizina. In the Kennicott shales of Dan, Chititu, and Young creeks the amount of stream cutting near the gulch heads has been very large. There is every reason to believe that on the south side of Chititu and on both sides of Young Creek the slopes were left smooth and free from gulches by the glacial ice. Since the ice retreated large gulches have been cut and a great amount of the easily eroded shale has been removed. The streams in these valleys have also succeeded in cutting through the thick gravels into the bed rock below.

Altogether, when the comparatively short time that has elapsed since the retreat of the ice from this area is considered, the work accomplished by erosional agencies has been surprisingly great.

ROCK GLACIERS.[a]

Among the important agencies of postglacial denudation in this district are the remarkable features which have been called rock glaciers (Pl. III, in pocket). These are rather widely distributed among the more rugged portions of the area, more than 30 occurring within the borders of this sheet. They are known to occur in other parts of the Wrangell Mountains, but here they attain exceptionally perfect development. An inspection of the topographic map shows at once many of the characteristics of the rock glaciers, but the important features, such as the surface markings, can not be shown with such a large contour interval. Although differing greatly among themselves in size, shape, and material, they have certain characteristics in common. They are usually long, narrow flows, many times longer than wide, confined in the bottoms of cirquelike valleys. Some have wide, fan-shaped heads and taper down to narrow tongues below; others are narrow above and spread out into spatulate lobes below; but the greater number are bodies of nearly uniform width, from one-tenth to one-fourth of a mile wide and from one-half to 2½ miles long. The surface slopes vary in different examples from 9° to 18° for the whole course of the flow.

On viewing one of the better-developed rock glaciers one is struck by its great resemblance to true glaciers. They all head in cirques and extend thence down the valleys. In cross section their shape is much like that of a glacier, being highest above the valley axis and sloping down sharply on the sides. Where confined in narrow valleys the rock glaciers are narrow tongues lying in the valley bottoms, but upon emerging from their restricting walls they spread out into broad lobes. Some have distinct lateral moraine-like ridges and all show a more or less well-marked longitudinal ridging.

The materials of which the rock glaciers are composed are the blocks and fragments of angular rock such as go to make up the ordinary talus slope, the fragments being derived from the walls of the cirque at the valley head. The variety of rock found in any

[a] Capps, Stephen R., Rock glaciers in Alaska: Jour. Geology, vol. 18, pp. 359–375.

rock glacier therefore depends on the materials found in the cirque walls—porphyry, limestone, greenstone, or shale, as the case may be. The individual rock fragments vary in size from fine stuff to blocks several feet in diameter in exceptional cases. Six inches would perhaps be the average size in these rock glaciers which are composed of porphyry, while in the greenstones and limestones the average is larger and in the shales it is smaller than this.

In many of the rock glaciers the fragmental rock extends all the way to the head of the cirque, with no ice visible and little or no snow on the surface. In several cases, however, the rock glaciers grade into true glaciers at their upper ends, without any sharp line of demarcation, so that there is a complete gradation between the two.

The surface markings are characteristic and in some measure are systematic in their arrangement. In the upper portions there are usually many parallel longitudinal ridges a few feet high, separated by troughlike depressions (Pl. IX, *B*, p. 56). Toward the lower end of each rock glacier which has an opportunity to spread out into a broad lobe the longitudinal ridges become less prominent and finally disappear entirely, giving place to concentric wrinkles which parallel the borders of the lobe. The sides of the flow below the cirque are usually separated from the rock valley walls by a sharp trough, and at their lower ends the flows steepen to the angle of rest for the material. The whole appearance gives one a decided impression of movement, as if the material had moved forward from the cirques in somewhat the manner of a glacier, the longitudinal lines simulating moraine lines.

The marked resemblance of these flows to glaciers led to the suspicion that ice must be in some way responsible for their movement. To determine if this were the case, a number of the rock glaciers, 7 or 8 in all, were dug into, and in each instance clear ice was found. This was not massive ice like that of a glacier, but interstitial ice, filling the cavities between the angular fragments and forming with the rock a breccia, with the ice as the matrix. The depth below the surface at which ice was found varied according to the elevation of the rock glacier and to the portion of it examined. Toward their lower ends the ice lay too deep to be found by any shallow excavations that there was opportunity to make. Farther up, toward the cirques in which they head, the ice was usually found within a foot or two of the surface if a depression was dug into. The surface of the ice-filled portion, being determined by the depth to which melting takes place, follows roughly the surface of the flow, so that along the troughs between the ridges running water could be found on a warm day following shallow channels in the ice-filled talus.

The rock glaciers are quite different from true glaciers, although in those cases where the rock glacier is a continuation of the lower end of a true glacier it may be impossible to draw a line separating the two. For the formation and existence of a glacier it is necessary that in the head of the basin occupied by ice there should be an annual surplus of snowfall over melt. When the amount of snowfall becomes less than the amount which melts and runs off, the glacier will dwindle and finally disappear. The greater number of rock glaciers, on the other hand, are found to head in cirques in which all or practically all of the winter snow disappears during the summer. In a true glacier, no matter how heavily moraine covered it may be, there is always a tendency to crevasse where the ice rounds a bend or passes over an irregularity of its bed, and great irregularity of surface is common at the lower end, where the melting ice allows the overlying moraine to cave in. In the rock glaciers no crevasses were seen, even in places where abrupt changes in the grade of the bed occur, and large cave-in pits are wanting. Irregularities of this kind, however, are not to be expected if the rock glaciers are composed, as they seem to be, of talus, with ice only in the interstices, for the talus itself is self-supporting without the ice, and the shape of the surface would be but little changed if the ice should all melt out. This is true, however, only of those flows which have not glaciers at their upper ends. Of those which head in glaciers, the upper ends would of course be profoundly altered by the melting of the ice, and these effects would be seen just as far down the flow as massive glacial ice had existed. The rock glaciers differ from true glaciers in that, although they advance spasmodically, they never retreat, for the flow retains its form even after the ice has melted out and motion has ceased. Little has been published concerning features of this kind. Certain "stone rivers" in the Falkland Islands have been described by Thomson,[a] Andersson,[b] and others, but according to Andersson's interpretation these "stone rivers," which are now streams of angular blocks of rock, were formerly composed of fine mud, with the blocks of rock buoyed up and carried along by the viscous flow of the mud. The movement has now ceased, and much of the fine material has been removed by running water.

The closest analogy to the rock glaciers seems to be found in the "rock streams" of the San Juan Mountains of Colorado, described by Cross and Howe[c] in the Silverton folio and more recently by Howe[d] in a separate publication. Both are composed of angular

[a] Thomson, Wyville, The Atlantic, p. 245.

[b] Andersson, J. G., Solifluction, a component of subaerial denudation: Jour. Geology, vol. 14, 1906, pp. 91–112.

[c] Cross, Whitman, and Howe, Ernest, Silverton folio (No. 120), Geol. Atlas U. S., U. S. Geol. Survey, 1905, p. 25.

[d] Howe, Ernest, Landslides in the San Juan Mountains, Colorado: Prof. Paper U. S. Geol. Survey No. 67, 1909.

talus from high mountains, and the similarities of appearance and surface configuration are striking. The San Juan flows have been referred to in a textbook[a] as "talus glaciers," and the authors are of the opinion that in many cases snow and ice have had some part in their development. Cross and Howe formerly believed that the position and form of the rock streams were due to glacial transportation, but the absence of ice and some other considerations led them to the opinion which they now hold, that the rock streams were formed by landslides which came down "with a sudden violent rush that ended as quickly as it started." Up to the present time no opportunity has offered to prove conclusively by a series of observations extending over a considerable period of time that these rock glaciers are in motion or to determine their rate of movement. There are, however, a number of significant facts which seem to make this conclusion necessary.

Although on account of climatic conditions most of the cirques in which the rock glaciers head are unable to support true glaciers, they are on the border line of glacial conditions, and although the snows may all melt away on the surface during the summer the ground remains permanently frozen a short distance below the surface and ice in the interstitial openings of a talus mass may remain unmelted indefinitely. Furthermore, a few of the rock glaciers have true glaciers at their heads which extend downward as far as climatic conditions are favorable and are continued below by rock glaciers whose ice is protected from the sun by the heavy coating of débris, and into such rock glaciers it is probable that a tapering tongue of true glacial ice extends down a considerable distance. But this glacial ice is not necessary to their movement, as is shown by those rock glaciers which are unconnected with true glaciers. In addition to the favorable climatic conditions, the exceptionally perfect development of these features in the Nizina district is due to the rugged character of the mountains, with cirques having steep heads and sides, and to unusually favorable conditions for rapid rock weathering and talus accumulation.

The history of the rock glaciers of this district is considered to have been as follows:

As the ice of the last great epoch of glaciation began to retreat and its area to contract, the head and side walls of many of the cirques, steepened by glacial undercutting and by bergschrund sapping, were exposed to the rapid weathering characteristic of bare rock surfaces in the high altitudes of this region. In many of the cirques the rock waste streamed down from the cliffs upon the glacier below and was gradually carried away by the ice and concentrated at its lower edge. Here in the usual order of events it

[a] Chamberlin, T. C., and Salisbury, R. D., Geology, vol. 1, 1904, p. 220.

would have been deposited as a terminal moraine, though differing in character from the common forms of terminal moraine in the preponderance of angular, talus-like material and in the proportionately smaller amount of mud and rock flour which form so important a part of the moraines of active glaciers. Here the small, fast-dying glaciers were eroding but little and were almost overwhelmed by the débris supplied them from the cliffs above. Into the débris toward the lower edge of the glacier the waters from melting ice and snow and from rains sank and froze and gradually filled the interstices up to a point below the surface where melting equaled freezing. In these ice-cemented masses a sort of glacial movement was started. As the climate became still milder, in many cirques the winter snows all melted away during the summer, so that conditions for ordinary glacial activity no longer existed, but the bodies of talus which reached the cirque floors became filled with interstitial ice and the consequent movement of the mass in a glacier-like way has continued, although no doubt all true glacial ice has now disappeared from many of the rock glaciers. It is certain that much snow is still carried down upon the surface of the rock glaciers in slides of snow and rock during the winter and spring, and considerable quantities of it may become covered by débris and incorporated into the rock glaciers, but this snow probably forms only a small part of the total mass of the flow.

The succession of events outlined seems to be well established in this region, where are now to be seen all the stages, varying from apparently active glaciers with short rock glaciers below to long rock glaciers in which no glacial ice is seen, in valleys where all the snow disappears during the summer; yet in these latter the slow movement seems still to be in operation, the rate of movement in each flow being controlled by the supply of talus from above and by the shape and grade of the floor over which it moves. The rock glaciers are therefore the true successors of real glaciers.

The rock glacier which lies on the west side of McCarthy Creek, three-fourths of a mile above the mouth of East Fork (Pl. VIII), though by no means the largest in size, offers a most instructive example for study, as it presents in a typical way many of the characteristic features of all of the flows. It heads in a glacial cirque in a mountain composed largely of porphyry but having many inclosed masses of black shale, the peaks at the cirque head reaching a height of 6,315 feet. The rock glacier occupies the cirque floor below an elevation of 5,250 feet, with talus slopes extending upward above it for about 200 feet. Above the talus the whole face of the mountain is of bare, rugged cliffs of porphyry and shale, both of

ROCK GLACIER ON McCARTHY CREEK THREE-FOURTHS OF A MILE ABOVE MOUTH OF EAST FORK.

Showing the source of supply in the talus cones above, also the surface markings—longitudinal in the upper portion, concentric below. See page 56.

A. ROCK GLACIER NEAR HEAD OF NATIONAL CREEK.

Showing the characteristic longitudinal ridges and their relation to the talus slopes on the rock walls above. See page 57.

B. HEAD OF ROCK GLACIER ON LITTLE NIKOLAI CREEK.

The cirquelike valley, with its abundant talus slopes feeding down to the rock glacier, is free from true glacial ice. See pages 53, 57.

which weather easily, so that the formation of talus is unusually rapid. The elevation of the valley head is not sufficient for the maintenance of a true glacier, and during the summer practically all of the snowfall disappears. By July 4, the time of observation, only small snow banks remained in sheltered places.

The rock glacier heads in the talus cones which have been built up at the base of the steep rock cliffs. These cones, although constantly added to by waste from the rapidly weathering cliffs above, have nowhere been able to attain large size, the materials evidently having moved on down the valley as a rock glacier as fast as they were supplied from above. From the base of each of the more vigorous talus cones a smooth ridge extends down the rock glacier, seeming to show that the forward movement has on the whole been uniform and continuous. Parallel longitudinal ridges of this kind characterize the surface of the upper three-fourths of the flow. The cirque basin above an elevation of 4,000 feet is a hanging valley, but below this level it joins the broad U-shaped valley of McCarthy Creek with an abrupt change of gradient. As it passes over the lip of the hanging cirque the rock glacier cascades steeply down the valley side, and on reaching the gentler slope below, being no longer confined by restricting valley walls, it spreads out in a great lobe along the valley bottom. In this lower lobe the longitudinal surface markings dwindle out and disappear, giving place to a set of beautifully developed concentric wrinkles which parallel the borders of the lobe (Pl. IX, *B*). The origin of these wrinkles is not clear, but they strongly suggest rings of growth and may represent the amount of annual movement of the rock glacier.

At its foot the flow has pushed across the valley bottom to the base of the east valley wall, thus indicating clearly by its position that it was formed after the retreat of the McCarthy Creek Glacier beyond this point. The creek has been crowded to the east and occupies a narrow channel between the foot of the rock glacier and the rock valley wall. The foot of the flow is being rapidly cut away by the stream and in places shows a face 75 to 100 feet high in which the slope is about 35°, or the angle of rest for the material. The creek, although of large volume and steep gradient, has been unable to do more than keep its channel open along the foot of the rock glacier, and it seems evident that the flow is moving forward as fast as the stream can cut it back.

Another rock glacier which heads in the same porphyry-shale mountain as the one just described flows in a northwest direction into the valley of National Creek, a tributary of the Kennicott (Pl. IX, *A*). It is remarkable for the unusually strong development of the longitudinal ridges in its upper portion, and these ridges show well their mode of origin in the separate talus slopes on the rock walls above.

The flow in Amazon Creek, just east of the Kennicott Glacier, and that in the north head of White Creek are notable for their great length as compared with their width and for the uniformity of their slopes from one end to the other. The surface of the former has a slope of 15° and that of the latter 12°.

The rock glacier which heads in the limestone mountain half a mile northeast of the Bonanza mine and flows eastward shows at its upper end all of the characteristics typical of these flows, but at the mouth of the hanging valley in which it lies it streams down to McCarthy Creek as a symmetrical talus cone (Pl. X, *A*). If the material had come down suddenly as a landslide, no such perfect talus cone would have formed, and its presence indicates that the material of which it is composed was supplied slowly. Furthermore, evidence that this rock glacier is still moving is given by the fact that the talus is still being supplied at the head of the cone and is invading the patch of bushes on its side.

The two large rock glaciers, one on the south and one on the northwest side of Sourdough Peak, are both of the type which originates in narrow cirques but spreads out into broad lobes below the point where the cirque walls restrict it. The glacier on the south side of this mountain is especially noteworthy on account of the great expanse of the flow below as compared with the narrow limits of the cirque in which it originated.

In conclusion, observation has led to the belief that these rock glaciers have moved and that many of them are still moving in much the same way as glaciers, and that, although glacial ice may be and doubtless is present in a few of them, it is not necessary to the movement, which may be due altogether to ice in the interstices. Furthermore, there is no evidence that the flows came down suddenly as landslides, but there are strong reasons for believing that they moved down slowly. The facts and considerations which have led to the conclusion that the flows did not come down suddenly but slowly and that some of them are now in motion are noted below.

1. The remarkable resemblance in position and form of the rock glaciers to true glaciers in the immediate vicinity.

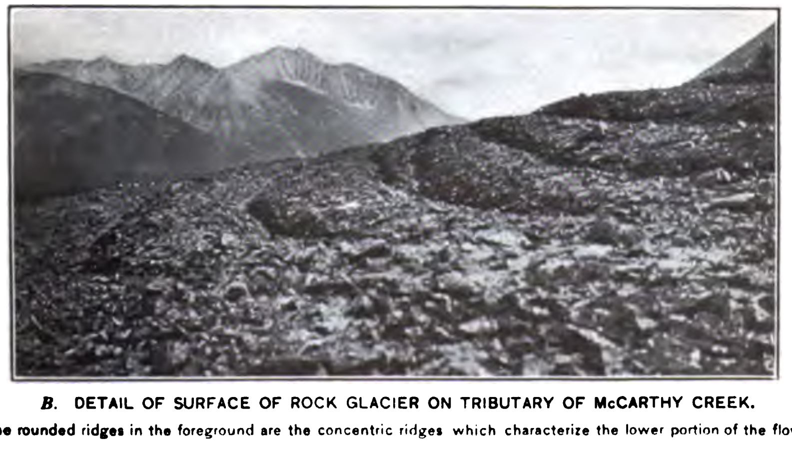
2. The direct connection and perfect gradation between true glaciers above and rock glaciers below.

3. The presence of interstitial ice at no great depth below the surface in all the rock glaciers which were dug into.

4. The longitudinal ridges of the upper portions of many of the flows that can be traced directly to active talus slopes.

A. ROCK GLACIER IN A TRIBUTARY OF McCARTHY CREEK NORTHEAST OF BONANZA MINE.

At the mouth of its hanging valley it breaks down into a great talus cone. See pages 58, 59.



B. DETAIL OF SURFACE OF ROCK GLACIER ON TRIBUTARY OF McCARTHY CREEK.

The rounded ridges in the foreground are the concentric ridges which characterize the lower portion of the flow.

5. Nowhere have the talus slopes at the cirque heads been able to form any considerable accumulations upon the surface of the rock glaciers. This seems to be strong evidence that the talus has moved down valley as fast as it has been supplied.

6. Most of the rock glaciers have a steep slope at the lower end, where the gently sloping surface of the upper portion breaks down at the edge at an angle of rest as steep as the material will retain. On this steep face the rock fragments show bare surfaces, while the talus on the surface above is usually lichen covered. This seems to show that the material is moving forward fast enough to prevent erosion at the lower end from establishing drainage lines on the face of the flow and from reducing it to a low-graded slope.

7. McCarthy Creek, a swift stream of large volume, which is now actively cutting into the lower edge of a rock glacier on its west side (described on pp. 56–57) that has been in existence long enough for large spruce trees to grow upon its surface, has so far been unable to do more than keep open a narrow channel along the foot of the flow. There is no evidence that the rock glacier ever extended 75 feet farther eastward to the rock bluff on the east side of the valley. It would be surprising if this mass of material, coming down with a violent rush, should have failed by just the width of the creek to cross the valley, and if the stream, which is now actively cutting into the face of the flow, should have been unable to do more than keep its channel open. It appears more probable that the slowly advancing edge of the rock glacier had forced the stream to its present position and that the edge of the flow is now farther advanced than it has ever been before.

8. There is no evidence that large landslides have taken place in this region if these flows are not landslides. None were seen below the miles of prominent cliffs of the area, though ordinary talus cones are abundant.

9. The rock glacier on McCarthy Creek, northeast of the Bonanza mine (Pl. X, *A* and *B*), ends below in a well-developed talus cone. If the material had come down suddenly as a landslide, no such perfect talus cone would have been formed. The presence of the cone indicates that the material was supplied slowly, enabling the cone to grow symmetrically. The cone is still growing, as can be seen from the way in which the talus from above is invading the patch of bushes on its face.

10. Wherever two rock glaciers from adjacent cirques join to form a single flow the point of junction shows that the two branches have flowed together synchronously, without any evidence that the flow from one branch has come down and overridden that from the other.

IGNEOUS ROCKS.

TRIASSIC OR PRE-TRIASSIC.

NIKOLAI GREENSTONE.

CHARACTER OF THE FORMATION.

The Nikolai greenstone resembles a sedimentary formation in its structural features. It is made up of flows of basaltic lava that succeed one another like beds laid down in water. The beds or flows are usually of considerable thickness, measured in tens of feet rather than in single foot units, and the bedded appearance is more evident when a large mass of the greenstone is seen from a distance great enough to give a comprehensive view of its larger features.

The color of the weathered surface is grayish green, but in places it has a reddish hue. A fresh surface is dark olive or grayish green. In texture it varies from a dense, rough, fine-grained rock in which individual crystals can not be distinguished to a medium-grained porphyritic rock. Many of the flows are amygdaloidal and have a spotted appearance, due to the cavity fillings. Some of the spots or amygdules are light gray or almost white, like quartz or calcite; others are dark green or gray. Quartz is present but is not so frequently seen filling cavities as calcite, yet these two minerals are not the only ones that produce light-colored amygdules. Amygdaloidal greenstone bowlders in Chititu Creek contain large spherulitic aggregates of white crystals, believed to be thomsonite. This rock, however, was not seen in place. Dark-colored amygdules are more common than the light ones and for the most part consist of chloritic or serpentinous material. In many places the cavities of the lavas were elongated and distorted before their present mineral filling was introduced, so that the amygdules have peculiar irregular forms. The cavities appear to have been distributed throughout the flows from top to bottom, for no evidence of their being more abundant at the upper than at the lower surface was observed. This is one of the reasons for suspecting that the lava was poured out under water, since the weight of the water resting on the surface of the lava would prevent in large measure the expansion of included gases or steam; yet it is admitted that no proof of their submarine origin has been discovered. Interbedded tuffs and shales were not found in the greenstone. Frequently a weathered surface of the greenstone is seen where the amygdules have been dissolved out, leaving a vesicular rock that probably resembles closely the original lava flow.

A newly broken surface of the greenstone would hardly lead one to believe that chemical alteration had taken place to any considerable extent, for the rock appears to be fairly fresh, yet microscopic examination of the sections shows that the alteration is advanced and is general.

The Nikolai greenstone is less obtrusive in its topographic expression than either the shales or the limestone. It forms steep slopes and ragged mountain tops, but the greenstone mountains do not possess the sharp, angular outlines of the shale mountains or the high wall-like cliffs and the pointed spires of the limestone. Neither do the lower greenstone hills present the smooth, rounded contours of the glaciated shale ridges on either side of Young Creek. The greenstone resists decay, but it has numerous joints and fracture planes and rapidly breaks down under northern climatic conditions. This accounts for the roughness of its ridges, the absence of smooth perpendicular cliffs, and the vast quantity of angular blocks below its large exposures. Such blocks do not disintegrate like the shales, so that greenstone pebbles and bowlders form a conspicuous proportion of the gravels and other unconsolidated deposits. The greenstone, like the Chitistone limestone, resisted strongly the distorting forces that are so plainly expressed in the folding of the McCarthy shale. There is even less evidence of folding than in the limestone, but it is apparent from field observations that adjustment to pressure by faulting has taken place extensively.

PETROGRAPHIC DESCRIPTION.

Thin sections of greenstone studied with the microscope show that the rock is a typical diabase now much altered. The principal constituents are feldspar and colorless pyroxene. The feldspar is labradorite, occurring in lath-shaped crystals, and in nearly every section is more or less altered. Pyroxene fills the spaces between the feldspars. It has been less resistant to alteration than the feldspar and is largely altered to a serpentinous or chloritic material. Accessory minerals are magnetite or ilmenite and chalcopyrite; olivine and iddingsite are rare. The principal alteration minerals are serpentine or chlorite, calcite, and perhaps quartz.

Cavities in the greenstone were abundant, but have been filled with secondary minerals such as chlorite, delessite, calcite, and, rarely, quartz. Many of the amygdules show an outer coating of chloritic material and an inner filling of radiating delessite crystals, in some sections associated with calcite. An opaque decomposition product is common.

DISTRIBUTION.

The Nikolai greenstone underlies conformably the Chitistone limestone and took part in the folding and faulting that the lower part of the limestone underwent. Its distribution, therefore, is related to that of the limestone, and most of its outcrops represented on the map lie in a narrow belt on the south of the limestone belt that is practically continuous and extends southeastward from the northwest corner of the mapped area to the head of Texas Creek. This belt has its greatest width on Nizina River. A branch extends eastward up Chitistone River and then southeastward into the valley of Glacier Creek, a northwestward-flowing tributary of the Chitistone just beyond the eastern limit of the area mapped. The ridge between Dan and Glacier creeks is capped by a broad, flat syncline of limestone pitching gently northwest, but the base of this ridge wherever it is exposed is greenstone. Greenstone is exposed on both sides of Chitistone River. It dips below the gravel floor of Nizina River north of the Chitistone but rises to view again on the west side and continues north half a mile or more till it is cut off by a fault beyond the limits of the area mapped.

In places only a veneer of conglomerate or shale of the Kennicott formation covers the Nikolai greenstone and small isolated patches of the greenstone appear where the thin covering has been removed. Such patches are seen about National Creek and south of Nikolai Creek. Two small patches of greenstone appear as islands in the gravels of Nizina River, and another, exposed through faulting and erosion, lies on the north side of Copper Creek.

THICKNESS.

It is impossible to determine the thickness of the Nikolai greenstone from observations in the area under consideration, for nowhere within this area is the base of the greenstone exposed. Furthermore, it is not certain that the base of the greenstone is exposed in other parts of Chitina Valley, although it is reported in the Chitistone River basin, and it seems probable that certain tuffaceous and shale beds in the Kotsina Valley may represent it.

The figures to be given represent, therefore, only that part of the formation exposed immediately below the Chitistone limestone—that is, the upper part. One of the best localities for measurements is on the east side of Nizina River, just north of Dan Creek. The dip of the limestone and greenstone is low to the northeast. Unless the greenstone is reduplicated by faulting, its thickness at this locality is at least 4,000 and possibly 5,000 feet. The conditions for measurement in the mountain on the west side of Nizina River are less favorable, but there appear to be not less than 4,500 feet of greenstone exposed there. About 2,000 feet are exposed on the east side of McCarthy Creek and 3,500 feet in the ridge on which the Bonanza mine is situated. Between Bonanza Creek and Kennicott Glacier a thickness of over 4,000 feet of greenstone is exposed. Faults are difficult to locate in the greenstone unless some of the other formations are present to give a clue to their existence, and it is recognized that faults of sufficient importance to impair the value of the measurements given may have escaped notice. It is highly probable, however, that the thickness of greenstone in the Nizina district approaches 4,500 feet, and there can be little if any doubt that it is over 4,000 feet.

Schrader and Spencer estimated roughly the thickness of the Nikolai greenstone in the upper part of Kotsina Valley at 4,000 feet.[a]

AGE.

Inasmuch as the Nikolai greenstone is composed of lava flows and so far as known does not contain intercalated fossil-bearing beds, the determination of its age depends on its relation to the formations with which it is associated. The greenstone may perhaps contain intruded sills of rock similar in composition to the flows, but for the most part it is made up of lavas that were poured out before the Chitistone limestone began to be deposited. It can not therefore be later than Upper Triassic. Unfortunately no evidence has been collected to fix a lower age limit. North of the Nizina district, in the valley of Skolai Creek and about Skolai Pass and the head of White River, the massive upper Carboniferous limestone is overlain by thin shale beds, tuffs, and lava flows. These overlying beds are believed to rest on the limestone conformably. The lava flows increase rapidly in amount as the succession is followed upward until they finally predominate. There is a possibility that the Nikolai greenstone represents the upper part of these lavas overlying the Carboniferous limestone, in which case their age would be Triassic. Brooks and Kindle have presented evidence to show that Triassic sediments along the upper Yukon rest conformably on limestone of the same age as the limestone on White River.[b] There is therefore some degree of probability that a similar relation of Carboniferous and Triassic formations of the Wrangell Mountains may sometime be established. A comparison of the Nikolai greenstone with the rocks south of Chitina River is of interest but throws little light on the age of the greenstone. The rocks south of the Chitina are chiefly sediments, schists, graywackes, and limestones, all much metamorphosed rocks. Their age is not known but they are usually referred to the Paleozoic. The degree of alteration in them is far greater than in the greenstone, and if this fact may be used as evidence the greenstone is considerably younger. With our present knowledge it is hardly possible to say anything more definite concerning the age of the greenstone than that it is older than the Chitistone limestone and probably is Triassic.

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[a] Schrader, F. C., and Spencer, A. C., The geology and mineral resources of a portion of the Copper River district, Alaska: Special publication of the U. S. Geol. Survey, 1901, p. 42.

[b] Brooks, A. H., and Kindle, E. M., Paleozoic and associated rocks of the upper Yukon, Alaska: Bull. Geol. Soc. America, vol. 19, 1908, p. 305.

JURASSIC OR POST-JURASSIC IGNEOUS ROCKS.

QUARTZ DIORITE PORPHYRY INTRUSIVES.

LITHOLOGIC CHARACTER.

Light-colored porphyritic intrusive rocks are abundant in the Kennicott formation and are confined almost entirely to that formation, for it is a remarkable fact that intrusives are rare in the Triassic sediments and the greenstone. These intrusive rocks occur in the form of laccoliths, dikes, and sills. They show considerable differences in texture and vary from fine-grained, almost aphanitic phases to distinctly granular phases in which larger crystals or phenocrysts of feldspar and quartz are included. The color, too, varies from almost white to creamy white and various shades of gray and brown. Small phenocrysts of quartz with perfect crystal outlines are common, but as a rule the more abundant feldspar crystals are less distinct owing to chemical alteration that has taken place. It seems rather remarkable that the rock should be so fine grained as it is in some of the larger intrusives and that it should have had so litle effect on the shales into which it was intruded.

The porphyries show many stages of alteration, from intrusions that look perfectly fresh to those in which the feldspars are almost wholly decomposed and the rock has a dull, lifeless appearance. A curious banded arrangement of alteration products was noted in some of the light-colored, fine-grained intrusives. Different stages in the advancement of alteration are indicated by concentric zones of yellowish-brown and white color, which show that the chemical changes proceeded in an orderly way from the surface toward the center of each joint block.

In many places large masses of black shale have been caught up in the body of an intrusive and stand out in a most conspicuous way against the lighter-colored porphyry background (Pl. XI, A). Some of these intruded shale masses are half a mile in length along their outcrops and give the appearance of thin shale beds between very thick porphyry sills. In general, however, the included shale masses are much smaller.

The porphyries resist decomposition but readily break down into slabs and angular fragments which give rise to extensive talus slopes, or "rock slides," as they are locally called. Such débris, because of its light color and its resistance to decay, gives character to slopes of loose material, and, although the dikes or sills from which it came may form only a minor portion of the rock mass, it almost completely hides the presence of shale or other kinds of rock.

Dikes and sills are numerous but present no unusual features further than that some of the sills persist for long distances and in

A. NORTH END OF PORPHYRY PEAK, SHOWING INCLUSIONS OF BLACK SHALE IN PORPHYRY.

See page 64.

B. PORPHYRITIC INTRUSIONS IN BLACK SHALE OF KENNICOTT FORMATION ON McCARTHY CREEK.

See page 65.

places take the form of long overlapping lenses. There is a marked tendency for the intruded rock to follow bedding planes rather than to cut across the beds, so that the sills are more numerous than dikes. Some of the sills in the black shales on the south side of Copper Creek valley continue uninterruptedly for several miles and are such distinct features that the prospectors have given them numbers, as the first, second, etc. They vary in thickness from a foot or two to 100 feet and give valuable aid in determining structure in the shales.

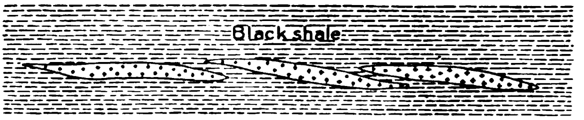

FIGURE 4.—Diagram showing the overlapping of lenticular porphyry sills in the black shales south of Copper Creek. Some of the lenses are 10 to 15 feet thick.

A good example of the way in which the porphyry dikes cut the black shales is given in Plate XI, *B*. (See also fig. 4.)

PETROGRAPHIC DESCRIPTION.

Microscopic examination of thin sections of the porphyry intrusives shows that perfectly fresh unaltered specimens are hardly to be found and that alteration products are practically always present. The rock has a fine-grained groundmass consisting chiefly of feldspar more or less altered and a little quartz in which are phenocrysts of feldspar and quartz. Various degrees of crystallization appear in the groundmass, but its perfection may be obscured by chemical alteration that has taken place since the magma consolidated. One or two of the sections studied are from specimens in which crystallization had not proceeded far when it was interrupted by cooling of the intrusive rock. These sections show a fine-grained groundmass, almost isotropic, filled with tiny forked skeleton laths or crystals of feldspar. Most sections, however, show a more advanced degree of crystallization. The feldspar is of the more acidic plagioclase variety. Zonal phenocrysts give an opportunity to determine that they belong mostly to the oligoclase-andesine series. Orthoclase appears in a few specimens. Quartz in rounded plates or with embayments is not uncommon, but for the most part the outlines are sharp and angular. Brown mica is usually present, as are also shreds and scales of colorless mica. Hornblende is the next most common ferromagnesian mineral. Many of the crystals are much altered, and in some sections the former presence of hornblende is known only by the decomposition products taking the form of the characteristic hornblende cross section. Pyroxene was found in one specimen. Most sections show a black metallic mineral like magnetite and brown iron-oxide stain.

Alteration begins in the feldspars and results in the production of fine scales of a highly refractory mineral, probably muscovite, that appear in fractures and along some of the zonal bands of the phenocrysts. Calcite is a common secondary mineral and results from the decomposition of hornblende and of feldspar, yet it may have been introduced in part by circulating water. Calcite resulting from decomposition of hornblende is associated with iron oxide.

DISTRIBUTION.

Porphyritic intrusions are present in the black shales of the Kennicott formation in all parts of the Nizina district, but they have their greatest development north of Nizina River. Porphyry Peak and Sourdough Peak are composed largely of porphyry, as is also the mountain north of Nikolai Creek. The upper parts of all three are made up almost entirely of porphyry in which are included masses of black shale. These laccoliths form a hard resisting cap on the softer shale base and doubtless have been an important factor in protecting the shale from erosion. There are no such large porphyry masses in the black shales southeast of Nizina River, but sills and dikes are numerous in all the shale mountains from Dan Creek to Young Creek. They appear to be more numerous on Dan and Copper creeks and about the head of Rex Creek than they are farther south, but the steep, bare sides of the mountains in the former locality give better opportunities for discovering them than the lower timber and moss-covered slopes of the latter. The preference shown by the intrusives for the black shales is considered as evidence that the molten rock was able to force itself into the black shales more easily than into the lower formations or the upper part of the Kennicott formation. It is remarkable, when one considers their number in the Kennicott formation, that so few intrusives are present in the Triassic sedimentary formations and the greenstone. Special attention was given to this point during the course of field work, since it was assumed that the intruding rocks must cut the older formations in order to reach the overlying younger formations and that traces of some of the conduits through which the melted rock rose would be found. A few dikes were discovered, but they do not seem to bear any proper relation in size and number to the amount of intruded matter in the shales, so that one is forced to conclude that the intrusives entered the shales through some channel not exposed.

AGE.

Intrusives in the Kennicott formation can not be older than the rocks into which they are intruded. Consequently they can not be older than late Jurassic or possibly early Cretaceous. No evidence bearing on their upper age limit was discovered in the Nizina district. It is perhaps true that the intrusions did not all take place at one time, and there might be cited as bearing on this point the fact that there is considerable variation in the composition and alteration of the intruded rocks. These two facts, however, are not in themselves proof. Such evidence as the intersection of one dike or sill by another dike or sill was not found, and it seems probable that the quartz porphyry intrusions belong to one period of intrusion.

Paige and Knopf have presented evidence to show that the quartz diorites of the Talkeetna Mountains are later than Middle Jurassic but younger than the late Jurassic, and state that they are "thus contemporaneous in a general way with that great series of batholithic intrusions of late Mesozoic age which affected the entire Cordilleran region from the Straits of Magellan to the Seward Peninsula of northwestern Alaska."[a] Quartz diorites of equivalent age intrude Upper Jurassic sediments in the Nutzotin Mountains northeast of the Wrangell Group.[b] There is a strong presumption that the quartz diorite porphyries of the Nizina district are but one manifestation of a disturbance that was widespread and of much greater importance in many other localities than it was here.

STRUCTURE.

Reference has already been made in the descriptions of the different formations to most of the structural features of the district, but for the sake of clearness these facts are here brought together in one section. Examination of the geologic map (Pl. III, in pocket) shows that in a general way the formations lie in zones extending in a northwest-southeast direction. Two sections are placed on the map to interpret the structure of these formations. They show that the prevailing dip of the formations below the Kennicott is toward the northeast but that the prevailing dip of the Kennicott itself is toward the southwest, and, further, that in consequence of the greater disturbances that have taken place in the older formations their general dip is considerably greater. Section *A–A* shows the synclinal structure of the Nikolai, Chitistone, and McCarthy formations along the northern boundary of the mapped area west of Nizina River. A parallel section northeast from any point on Dan Creek to Chitistone River or Glacier Creek would have shown this synclinal structure but with the syncline much flattened out, and a comparison of such a section with section *A–A* and the map would show that the synclinal axis pitches gently northwest. Section *A–A* also shows the unconformable relation of the Kennicott to the older formations, its comparatively low southwesterly dip, and the fault that here displaces the basal beds of the Kennicott and the Nikolai greenstone. Section

[a] Paige, Sidney, and Knopf, Adolph, Geologic reconnaissance in the Matanuska and Talkeetna basins, Alaska: Bull. U. S. Geol. Survey No. 327, 1907, p. 20.

[b] Moffit, Fred H., and Knopf, Adolph, Mineral resources of the Nabesna-White district, Alaska: Bull. U. S. Geol. Survey No. 417, 1910.

B–B shows the Kennicott formation dipping gently to the southwest in broad open folds. The southwest dip is small but is sufficient to bring the interbedded shale and sandstone forming the upper part of the Kennicott formation well down on the slope of the mountains south of Young Creek, although these beds appear only on the tops of the high mountains south of Copper Creek and about the head of Rex Creek. At the northeastern end of this section the greenstone and the limestone lie almost horizontally, but a displacement has taken place by which the limestone is brought into contact with the black shale of the Kennicott formation, and it appears that near the fault plane the limestone dips to the southwest or toward the fault.

Faulting is of common occurrence in the Nizina district, but with the exception of the fault shown on the two sections most of the displacements are comparatively small in amount. The great fault just referred to is a strike fault—that is, its trend is the same as the prevailing strike of the formations and it extends from Copper Creek northwestward to McCarthy Creek. From work done in previous years it is known that this great fault continues westward beyond the Kennicott Glacier, but its course there has not been traced.

Good opportunities for studying the fault were found at two localities, one on the South Fork of Nikolai Creek and the other on Dan and Copper creeks. The north slope of the South Fork of Nikolai Creek is a dip slope formed by a thin veneer of basal Kennicott beds resting on greenstone. (See section *A–A*, Pl. III.) The south slope shows the basal Kennicott in the creek with a narrow belt of greenstone above it and above the greenstone a great thickness of Kennicott dipping to the southwest. The Kennicott and Nikolai formations in this locality were displaced by a fault in such a way that the rocks on the south side now have a relatively higher position than those on the north side. The fault dips high to the northeast and the displacement is about 800 feet. Very different conditions prevail on Dan and Copper creeks. Section *B–B*, Plate III, shows that the north slope of Dan Creek is formed of Nikolai greenstone and Chitistone limestone lying in a practically horizontal position. This condition does not hold on the south side; instead a great block of limestone abuts against black Kennicott shales and forms the point of the obtuse angle between Dan and Copper creeks. In this locality the displacement involves a raising of the north side relatively to the south side, exactly the reverse condition from that in the Nikolai Creek locality. This fault dips about 60° NE. on Dan Creek and, although complicated by minor cross faults, has a displacement that seems to be nearly or quite the thickness of the Chitistone limestone.

The same relative movement as that on Dan Creek took place on the two sides of the fault on the west side of Kennicott Glacier—that is, the formations on the north side were raised—yet no direct evidence was discovered to prove the existence of the fault between the glacier and McCarthy Creek.

Faults of this kind in which the relative movements of the two walls are opposite in direction at two different localities are known elsewhere, yet, inasmuch as the gravels of Nizina River prevent the demonstration that the Dan Creek fault is continuous with that of Nikolai Creek, it should be stated that the conditions described might result from the dropping of a block between two parallel faults, in which case we should be dealing not with one but rather with two faults. No evidence was seen in the field to raise a suspicion that two closely spaced faults occur here. A perpendicular fault almost parallel with the Dan Creek fault traverses the Young Creek valley, and a third, whose strike is more nearly east and west, crosses Nizina River a short distance north of the limits of the area mapped. The Young Creek fault is probably of the same order of magnitude as that of Dan Creek but is more difficult to study, since only one formation is concerned in the localities where it was examined. It has a known horizontal extension of 5 or 6 miles and the zone of disturbance is a wide one. These displacements, however, throw no light on the problems of Dan and Nikolai creeks.

The three faults just mentioned are the most prominent ones of the Nizina district, but they are not the only ones. There is evidence in many places of movement of the greenstone and limestone formations along their plane of contact, but measurements of displacement under such conditions are difficult. Undoubtedly faults are present in many places where they have not been recognized, for it is only under favorable conditions that they are discovered. Such conditions are provided by the limestone-greenstone contact. The character and frequency of faulting are shown on the geologic map by the contact north of Dan Creek. Displacements of the kind occurring there are difficult to recognize and to trace where only one of the formations is present. Most of the observed minor faults make obtuse angles approaching 90° with the major strike faults and are vertical or nearly so. They are present in many places and are commonly of small displacement in comparison with the strike faults even when of considerable horizontal extension. The shear zone of the Bonanza ore body is of this class. It was traced in a direction N. 30° E. from the mine for a distance of 1 mile, but the displacement at the limestone-greenstone contact is only 2 feet. A parallel fault on the east side of McCarthy Creek has a displacement of over 500 feet. The numerous faults north of Dan Creek are vertical or nearly so and have displacements ranging from 10 or 15 feet to several hundred feet. Minor strike faults were also noted, but since they do not cut bedding or formation boundaries they are apt to be undiscovered, as are also faults of low dip, such as the horizontal fracture planes of the Bonanza mine, along which slight movement has taken place.

In summarizing what has been said about faulting attention is directed to the fact that in a broad way the faults may be divided into two classes, those parallel to the prevailing strike of the formations and those that are approximately perpendicular to it. These may be referred to as strike faults and dip faults, for they are vertical or approximately so, and their strikes correspond in a measure with the direction of strike and dip of the formations.

The principal strike faults have given rise to great displacement of the rocks cut by them and persist for long distances horizontally. The dip faults are more numerous but the displacements are smaller. The effects of these faults on the rocks may be compared to the fracturing of the ice in a glacier. Blocks were formed which had to adjust themselves to surrounding conditions; some of them moved up, some down, as will be seen by examining the limestone-greenstone contact north of Dan Creek. In this way adjustments of great amount were brought about by many small, widely distributed displacements.

AREAL GEOLOGY.

The areal distribution of each formation has been indicated in the description of the formation. It now remains to bring these scattered facts together in one brief statement. Fully one-third of the mapped area is occupied by unconsolidated gravels, sands, etc., of glacial and fluvial origin (Pl. III, in pocket). Two-thirds of the remainder is given to the Kennicott formation. Consequently less than one-fourth remains to the rocks older than the Jurassic. The greenstone, the limestone, and the Triassic shales are confined strictly to a belt along the northeastern side of the area, but their territory is invaded in a few places by outliers of the overlying basal beds of the Kennicott formation. Triassic shales occupy only a small part of the area belonging to the older rocks, for the map does not extend far enough north to include the places of their greatest development. They are seen along the boundary of the mapped area between McCarthy Creek and Nizina River and in the vicinity of Copper Creek. The Nikolai greenstone and the Chitistone limestone form a narrow belt that extends northwest from Pyramid Peak to Kennicott Glacier. Nothing but Kennicott sediments and the igneous rocks intruded in them appears south of the Triassic formations. They appear in two principal areas on the two sides of Nizina River and are separated by a broad stretch of gravel deposits. Quartz diorite porphyries cut the Kennicott sediments in all parts of the district but find their greatest development in the black shales, particularly the shale area north of Nizina River. The porphyry sills of Copper Creek are conspicuous because of their persistence, but the intrusives of Porphyry and Sourdough peaks are so much greater in amount that they dominate in the upper parts of these mountains.

It may not be out of place to state here that the four formations of the Nizina region continue northwestward beyond Kennicott Glacier and that their areal relations there are practically the same as on the east side. Black Kennicott shales with numerous porphyry intrusives make up the mountains west of Porphyry Peak on the opposite side of Kennicott River, and the greenstone and Triassic sedimentary formations appear north of Fourth of July Pass. The mountain in the middle of the glacier, known as "The Peninsula," gives an excellent section of the greenstone and the two Triassic formations. Greenstone forms the southern point of "The Peninsula." On it lies the northeastward-dipping limestone, which is succeeded in turn by the Triassic shales. This locality is one of a few in this region where the limestone has been closely folded and much contorted.

It is known regarding the extension of these formations toward the southeast that the greenstone outcrops on Canyon Creek east of Young Creek, and it is probable that both greenstone and limestone extend still farther eastward into the Chitina Valley. Schrader traced the black Jurassic shales, which were at first thought to be Triassic, as far east as Canyon Creek, but beyond that there is no information concerning them.

HISTORICAL GEOLOGY.

SEDIMENTARY AND IGNEOUS RECORD.

In describing the formations of the Nizina district the rocks of sedimentary origin were considered in one group and those of igneous origin in a second. This treatment by family groups is not followed in the discussion of the historical geology of the district, but rather it is attempted to give in the order of their occurrence the geologic events connected with the different rocks.

The first event in the geologic history of the district concerning which we have evidence within the district is the outpouring of lavas that are now known as the Nikolai greenstone. This took place previous to the deposition of the Chitistone limestone, and consequently either in Upper Triassic time or in some period preceding it. It is not, probable, however, that the greenstone flows are older than the Triassic, since the best evidence at hand indicates that they are later than Carboniferous. The flows did not take place as a single event but were doubtless continued through a considerable time interval. There is some reason to believe that they may have been poured out under water, although it is by no means established that such is the case; yet, whether they accumulated in the sea or whether they accumulated on land and were later carried below sea level by subsidence of the land, the beginning of deposition of Upper Triassic marked the complete cessation of volcanic activity for the time being. Deposition of the Chitistone limestone continued for a long interval of time without important changes in the character of the material laid down. At first the conditions of accumulation were relatively stable and the massive beds at the base of the Chitistone were formed, but later conditions changed, for the beds grew thinner, and finally thin partings of shale began to appear. The commencement of shale deposition marked the beginning of the transition from the Chitistone limestone to the McCarthy shale. As the shale beds increased in amount the limestone decreased, till finally shale predominated and limestone was no longer of importance in the formation. All these events that concern the sedimentary formations took place before the end of the Triassic period. They terminated with an elevation of the Triassic sediments above sea level, which was accompanied or followed by deformation and folding of all the sedimentary beds and the greenstone. Erosion of the new land surface began as soon as elevation took place and, unless part of the historic record has been lost or overlooked, continued throughout Lower and Middle Jurassic time. During this erosion period an enormous quantity of material was removed from the land and returned to the sea, but what became of it is not known. The beveled edges of the greenstone, the limestone, and the shale bear evidence of an areal extension of these formations beyond the limits now recognized and testify to the thousands of feet of material carried away.

Erosion was at last interrupted by the advance of the Jurassic sea. This advance probably took place from the west, where it began in Lower Jurassic time, as is known from the presence of Lower Jurassic beds on Cook Inlet. Upper Jurassic sea prevailed in the Chitina region long enough to permit many thousand feet of sediments to accumulate. This sea is supposed to have been a somewhat restricted one. The waters were shallow. Probably a land mass existed to the south in the region of the present Chugach Mountains and separated the sea from the ocean. The sediments deposited in the Jurassic sea are not all of one kind and were deposited under varying conditions. The Kennicott formation bears within itself evidence of many and important changes during the time when it was being laid down. Shore conditions are indicated by the basal conglomerate, but the gradual upward decrease in size of the pebbles that form the conglomerate and the transition from conglomerate or grit to sandstone and from sandstone to fine black shales tell of a progressive change in conditions that is difficult to interpret, for it may have been caused in various ways. The great thickness of fine black shale, however, is evidence of long-continued stability in the source of supply and the manner of deposition of the materials composing them. Stability at last gave place to instability, and another great thickness of interbedded shales and sandstones followed the black shales till the last known event of Upper Jurassic deposition took place and the massive upper conglomerate was laid down. Deformation, elevation above sea level, and intrusion by quartz diorite porphyry are the next events recorded in the rocks of the mapped area, and they lead up nearly to the beginning of development of the present topography. Yet there is reason for assuming that the Kennicott formation does not represent the latest rocks of the Nizina district and that other younger sedimentary and igneous rocks may have once been present but are now entirely removed. This assumption is based on the presence of coal-bearing beds and still younger lava flows in the vicinity of Fourth of July Creek, west of Kennicott Glacier, and on the head of Chitistone River. Neither of these localities has been studied in detail. The coal of Fourth of July Creek is confined to a small area. It lies horizontally, is associated with black carbonaceous shale, and is overlain by arkose sandstone and an andesitic lava flow. Its relation to the great fault that cuts the Kennicott and older formations is such as to leave little doubt that it was deposited after faulting took place, and it is provisionally referred to the Tertiary. Coals associated with shales and sandstones and overlain by lava flows are exposed on Chitistone River. These beds also are referred to the Tertiary. The presence of these younger rocks in the immediate vicinity makes it appear highly probable that they may have extended into the region under consideration, since it is difficult to understand how they could have been deposited where they now appear without being much more widespread than they are. A coal-bearing formation consisting predominantly of coarse arkose and showing no evidence of marine conditions, but included between marine Tertiary formations, reaches a thickness of more than 2,000 feet in the Controller Bay region.[a]

More than 3,000 feet of fresh-water coal-bearing Tertiary sediments are exposed in the Matanuska region.[b]

These sediments comprise "a series of sandstones, shales, arkose, numerous coal seams, and a large volume of conglomerate." The Gakona formation of the Copper River basin[c] is a coal-bearing for-

[a] Martin, G. C., Geology and mineral resources of the Controller Bay region, Alaska: Bull. U. S. Geol. Survey No. 335, 1908, p. 31.

[b] Paige, Sidney, and Knopf, Adolph, Geologic reconnaissance in the Matanuska and Talkeetna basins, Alaska: Bull. U. S. Geol. Survey No. 327, 1907, p. 27.

[c] Mendenhall, Walter C., Geology of the central Copper River region: Prof. Paper U. S. Geol. Survey No. 41, 1905, p. 52.

mation of fresh-water origin. It reaches a thickness estimated to be not less than 2,000 feet and includes 500 feet of conglomerate, together with shale, gravel, sand, and lignite beds. Other areas of supposedly Tertiary sediments appear in the Copper River valley, but very little is known about them. If the coal-bearing rocks occurring just north of the Nizina district are of Tertiary age, it is a reasonable presumption in the absence of definite proof that they, like the coal-bearing Tertiary formations of the Matanuska and Copper River basins, are of fresh-water origin, and that therefore there is no necessity for assuming a submergence of the region below sea level after the Kennicott formation was deposited. The element of doubt in this presumption lies in the uncertainty concerning the age of the coal, for it is known that the Upper Jurassic formations as well as the Tertiary formations of the Matanuska region carry coal.

PHYSIOGRAPHIC RECORD.

There is good evidence in many parts of Alaska to show that at the time when the Tertiary coal formations were deposited the land had a much lower relief than it has to-day. The present mountain ranges, although perhaps distinctly outlined, had not yet reached their full development. The coal formations were laid down in depressions of a land surface that must have lacked in large measure the rugged character that we now see. Probably this land surface presented many of the features of the present Copper River or Yukon valleys in their broader parts. Such appear to have been the conditions when the forces that resulted in the uplifting production of the present Chugach Mountains and the Alaska Range began to be felt. These forces doubtless acted slowly, but they acted for a long period of time, and they may be in operation yet. They brought about the uplift of the mountain areas and made it possible for the agents of erosion to initiate the work of forming the present mountain and valley features. They were accompanied by or were the cause of the extrusion of a great volume of lava that has continued almost to the present day and is the most characteristic feature of the Wrangell Mountains, the feature that distinguishes them from the Chugach Mountains on the south and the Alaska Range on the north.

Chitina Valley is a very old topographic feature and was formed by a stream that probably had an outlet by way of the upper Copper River valley either into the drainage basin of Cook Inlet or possibly into the Yukon Valley. Its axis coincides with the boundary line between the older metamorphic rocks of the Chugach Mountains and the younger, less-altered rocks on the north side of the valley. This boundary in part marks an unconformity of deposition and possibly also one of faulting, but in either case it appears to have been a determining factor in locating the position of the valley. The valleys of Nizina River and the other streams of the Nizina district, like the Chitina Valley, originally represented the work of streams alone and were the result of normal stream erosion, but they have been profoundly modified by the action of glacial ice. This modification is represented chiefly by changes in valley forms due to straightening of the sides, alterations in the form of cross section, and lowering of the valley floors, together with changes brought about by the deposition of unconsolidated glacial materials. These modifications having already been described in the section on glaciation, it is unnecessary to repeat their description here. It is only necessary to say that the most conspicuous topographic features we see to-day owe their present appearance to recent glaciation, yet that subsequent stream cutting and rapid subaerial erosion due to the subarctic conditions have begun to modify the land forms left by the retreating ice. These later features are seen in the rock-walled canyons on the lower courses of all the streams, the deep gulches such as cut the Kennicott formation on White and Young creeks, and the great accumulations of loose material in the form of talus.

ECONOMIC GEOLOGY.

HISTORY.

The history of mining in the Chitina Valley begins with the rush of prospectors to Valdez in 1898. These men were influenced by the gold discoveries in the Yukon Basin during the preceding two years and came to Valdez in the hope of finding an easier route to the Yukon or new placers in the Copper River valley. Reports of copper on Copper River had circulated since the time of the Russians, who found in the hands of natives copper that probably came from the Nizina district, yet a majority of the prospectors were in search of gold, not copper. A few, however, turned their attention to copper and crossed from Valdez to the Wrangell Mountains, where their efforts received encouragement. In the following year (1899) the search for valuable minerals was resumed and prospecting parties ascended Chitina Valley as far as the Nizina district. It is doubtful if they attempted to go farther east in the main valley, and for that matter there has been little effort to prospect the upper Chitina region in the years since then. The Nikolai copper lode was shown to a party of white men by a native sent for this purpose by Chief Nikolai, of Taral, in July, 1899. Nikolai's house was at the mouth of Dan Creek, and the ore body was doubtless discovered by the natives on some of their hunting expeditions. It is usually difficult to reconcile the statements of different persons concerning the early events connected with the history of a new country, and the Nizina district is no exception to the rule. It is said that gold was discovered on both Dan and Young creeks at about this time, but either the quantity found was small or the difficulties met prevented any immediate steps toward developing the property.

Work was begun on the Nikolai mine in 1900 for the purpose of securing a patent to the claim. Some of the men who were interested in the property devoted part of their time to further prospecting, and in this way the large body of chalcocite named the Bonanza ore body was discovered about the end of July or the first of August (1900) by C. L. Warner and Jack Smith. It was discovered independently a short time later by Spencer, of the United States Geological Survey, who was engaged in mapping the contact of the Nikolai greenstone and the Chitistone limestone. Up to this time interest in gold placers had been secondary to that in copper prospects, but the presence of gold on Dan Creek was not forgotten, and in 1901 the creek was staked by C. L. Warner and D. L. Kain for themselves and others. Mr. Kain was known to his companion as "Dan," and they named the creek after him.

The first men to find gold on Chititu Creek were Frank Kernan and Charles Koppus, who came to the creek in the first part of April, 1902. They were joined shortly afterwards by two others, Messrs. Rowland and Dimmet, and these men staked the creek for themselves and their partners on April 25. News of the Nizina strike quickly reached the outside, and by July of 1902 the stampede was under way. A new town sprang up on Chititu Creek and was quickly provided with all the usual elements of a thriving placer camp, but there was not enough placer ground to support all comers, and most of the population soon vanished. The richest and most easily mined gravels were largely worked out in the first years by pick and shovel, but since that time the claims on both Chititu and Dan creeks have become more and more consolidated in the hands of a few owners, who are preparing to handle their gold-bearing gravels on a larger scale by more economical methods.

A similar consolidation of ownership has taken place in the case of the Bonanza mine, so that now instead of 11 principal ownerships, some of them representing two or more persons, the property is controlled by a single strong corporation capable of supplying the large capital necessary to develop the ore body.

The mineral production of the Chitina Valley to the present time consists entirely of gold, which is practically all from Chititu and Dan creeks. Copper has not been produced in a commercial way because there is no means of getting it to the coast, so that all the copper brought out is that taken for samples and assays.

COPPER.

OCCURRENCE OF THE ORES.

GENERAL STATEMENT.

An examination of the copper prospects of the Chitina Valley was made by members of the United States Geological Survey in 1907, and a report of that work was published in bulletin form later.[a]

Since that time there has been considerable advancement in the development of some properties and a few discoveries have been made, yet the results of the work done have thrown no light on the nature of the changes which take place in the ore bodies as distance from the surface increases. This question, excepting that of the amount of ore present, is probably the most important one concerning the copper deposits of the region. A study of the copper deposits on the eastern side of the Wrangell Mountains[b] has shown that copper occurs there under much the same conditions as in the Chitina Valley and has suggested some further ideas as to the origin of the ores. The descriptions and discussion that follow, then, are based partly on previous work but have received such revision and addition as have been found to be necessary.

Copper ores in the Chitina Valley north of the river occur in three ways—as copper and copper-iron sulphides associated with the Nikolai greenstone and with the Chitistone limestone; as native copper associated with the greenstone; as placer copper accompanied by native silver and gold. The important copper minerals are chalcocite or copper glance, bornite, chalcopyrite, and native copper. In every copper prospect there is a small quantity of one or more of the oxidation products, such as green malachite stain, azurite, and less frequently the red oxide, cuprite. Chalcanthite, or blue copper sulphate, and the black oxide, tenorite, are rare. Covellite is associated with chalcocite in some localities.

The ore bodies occur as replacements of greenstone or of limestone or as fillings in cavities developed along fault planes, shear zones, or joint planes in greenstone or limestone. A few examples are known of ore bodies to which the term "fissure vein" might be applied in its popular sense, but by far the greater number of the copper deposits are aggregates of copper minerals forming ore bodies of irregular shape which are well described by the term "bunch deposits," yet even the "bunch deposits" are believed to owe their existence to the presence of faults or fractures that permitted the circulation of copper-bearing solutions. Aggregates of copper min-

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[a] Moffit, Fred H., and Maddren, A. G., Mineral resources of the Kotsina-Chitina region, Alaska: Bull. U. S. Geol. Survey No. 374, 1909.

[b] Moffit, Fred H., and Knopf, Adolph, Mineral resources of the Nabesna-White district, Alaska: Bull. U. S. Geol. Survey No. 417, 1910.

erals are far more common in the greenstone than in the limestone. but the largest deposits that have been discovered up to the present are in limestone. Most of the deposits in limestone are near the base of the Chitistone formation, yet there are a few notable exceptions to this general rule. On the other hand, the attempt to show that deposits in the greenstone are most apt to occur near or at the limestone-greenstone contact was not successful, and the field evidence seems to indicate that copper occurs in nearly all parts of the formation and that the location of ore bodies is dependent only on favorable conditions of supply or for deposition.

COPPER SULPHIDE DEPOSITS IN GREENSTONE AND LIMESTONE.

Although this part of this paper is intended to deal only with the copper prospects of the Nizina district, it is necessary in the description of the ores to consider the district in its relation to the rest of the Chitina region. The best examples of copper sulphides in greenstone are not found within the region under consideration but to the west of it. The copper minerals are bornite, chalcopyrite, and chalcocite, with secondary alteration products, and they occur (1) in irregularly shaped ore bodies without any conspicuous amount of associated gangue minerals or (2) as well-defined veins accompanied by a gangue of calcite and quartz. Ore bodies of the first kind occur in shear zones or in jointed or shattered portions of the rock. The copper minerals fill fractures in the rock, or more commonly they replace the rock itself. Bornite and chalcopyrite are of more common occurrence than chalcocite, yet some of the most promising ore bodies in the greenstone consist chiefly of chalcocite.

A careful examination of the many copper prospects leads to the belief that most of the ore bodies are of the "bunch deposit" type and are a replacement of the greenstone by copper minerals carried in solutions that circulated along fracture planes produced by jointing, shearing, or faulting of the country rock. The mineralized parts of the greenstone are without definite boundaries in many places, and the ore grades from solid sulphides to disseminated grains or particles scattered through the greenstone, which grow fewer and fewer as distance from the fractures increases till they disappear altogether. Sections of ore examined under the microscope show that the two sulphides bornite and chalcopyrite are closely associated and are intermingled in such a way as to suggest that they were deposited at the same time. Chalcopyrite is practically always present, even in ore that appears to the naked eye as pure bornite. Chalcocite accompanies the bornite and chalcopyrite in some specimens, and the association is such as to suggest that the chalcocite was derived from the poorer sulphides, but this was not definitely proved. A few of the deposits in greenstone consist entirely of chalcocite.

The vein deposits accompanied by gangue minerals are associated with well-defined faults in all the best examples. The copper minerals are bornite and chalcopyrite, and the gangue is chiefly calcite accompanied by quartz. Epidote is commonly present also. The veins pinch and swell markedly in short distances and in all the localities where they were examined have been subjected to faulting or other movement since their deposition.

Copper deposits in limestone were formed by replacement of the limestone as a whole by copper minerals in solutions circulating along fracture planes such as faults, shear zones, or joints. The copper minerals are chalcocite and bornite, accompanied by malachite, azurite, and in places covellite as alteration products. As a rule, the boundary between ore and country rock is distinct, although the form of the ore body itself may be very irregular. This is particularly true where the copper mineral is chalcocite. In deposits of bornite in limestone a dissemination of the copper mineral through the adjacent country rock was noticed, and in such examples there is a gradation from ore to country rock similar to that in the greenstone deposits. One of the best examples of this kind shows a large proportion of chalcocite associated with the bornite, and the deposition of the copper was accompanied by a thorough silicification of the limestone. Large masses of chalcocite like that of the Bonanza property are distinctly replacement deposits in fracture zones. No fragments of limestone are included in the body of the ore, although isolated masses of chalcocite are scattered through the limestone. The ores are most frequent near the limestone-greenstone contact, yet some of them must be fully 1,000 feet above the base of the limestone. It is a notable fact that azurite is far more common as a secondary oxidation product in the limestone replacement deposits than malachite and that it is not common in the deposits in greenstone. Small veins of azurite with cores of chalcocite show distinctly that the azurite in the Bonanza mine was produced by the alteration of chalcocite. Covellite originated in a similar manner.

NATIVE COPPER ASSOCIATED WITH THE GREENSTONE.

Native copper is associated with amygdaloidal phases of the Nikolai greenstone and is also found accompanied by quartz or by quartz and epidote in veins cutting the greenstone. Most commonly it occurs as grains and small slugs in the amygdules and disseminated through the greenstone and as films or leaves and small veinlets cutting the greenstone. Tabular masses deposited in joint planes without much doubt indicate the way in which the large masses of native copper and the copper nuggets in the Dan and Chititu placers were formed. Such masses found in place on the head of White River are believed to have resulted from the alteration of chalcocite. In a few places in the tributary valleys of the Chitistone and Kotsina rivers native copper occurs in amygdaloidal greenstone in association with a mixture of copper oxide and carbonaceous matter, filling vesicles and fractures in the lavas. Such native copper as is known in the Nizina district is probably due to the reduction of previously formed sulphides or oxides, yet primary native copper is known on the head of White River. There is a strong similarity between the native copper-bearing greenstone of Chitina Valley and the amygdaloidal copper ores of Lake Superior. Specimens from the two regions could be selected between which it is doubtful if close observation could distinguish. This similarity would also extend to the disseminated sulphide ores in greenstone if by any means the sulphides could be altered to native copper.

PLACER COPPER.

Native copper is associated with silver and gold in the gravels of Chititu and Dan creeks. It occurs in pieces that range in size from fine shot to masses weighing several hundred pounds. Two or three tubs of fine copper are secured at each "clean-up" of the sluice boxes on Chititu Creek and give much difficulty in cleaning the gold, since the finest of the copper has to be removed by hand. Many of the nuggets contain native silver, which shows that the copper and silver are here closely associated in origin. The remarkable similarity in form and appearance between the copper nuggets of the Nizina district and the larger masses of copper taken from the stamp mills of the Lake Superior region is evident to anyone who compares the two, since the chief differences are that the placer copper has a slightly smoother surface and an oxidized coating. The copper and silver are derived wholly or in part from the greenstone. Assays of chalcocite from the Bonanza mine and from other copper ores of the Nizina district have shown the presence of both silver and gold in the copper deposits. Small particles of native silver were found in a freshly broken specimen of greenstone from a bowlder on Chititu Creek, and an assay of the rock also showed its presence. The silver was associated with calcite in small fractures. Silver nuggets up to 7 pounds in weight have been found on Dan and Chititu creeks, but where silver is associated with copper in the same nugget copper predominates, and in general silver is seen only as small particles in the copper. Copper is found only in those tributaries of Dan and Chititu creeks where greenstone pebbles and bowlders form part of the stream gravels; consequently it occurs only where the gravels have been formed in part by streams flowing through greenstone areas or where there is a foreign element in the gravels that was derived from a greenstone area and brought to its present position by glacial ice.

ORIGIN OF THE COPPER DEPOSITS.

It is not yet possible to give a satisfactory account of the origin of the copper deposits, but some features of their history can be stated with a considerable degree of certainty, and it is desirable to do this, since it may be of value in future development work. A history of the present deposits is concerned chiefly with three problems--the source of the copper minerals, the manner in which they were brought to their present position and deposited, and the changes that have taken place in them since they were deposited.

It is believed that the source of the copper is within the Nikolai greenstone itself and that only a very small part, if any, is derived from an outside source. The chief argument in favor of this view is the widespread and almost universal occurrence of copper minerals in the greenstone wherever it is exposed. This is seen in hundreds of places in all parts of the formation, from the west end of the Chitina Valley to Nizina River and the upper Chitina. Wherever fractures in the greenstone have permitted water to circulate the green copper stain is apt to be found. Probably the copper was originally present in the form of sulphide in the lava flows, but this does not exclude the possibility of its also having been combined in other minerals of the rock. Pyrite and chalcopyrite are of common occurrence in the greenstone, as is proved by both the hand specimens and the thin sections examined under the microscope. This source is believed to be adequate for supplying all the copper concentrated in the present ore bodies.

An examination of the greenstone in many places has shown that considerable chemical alteration in its constituent minerals is universal. No fresh and unaltered specimens of the rock were found. Alteration began first and is greatest in the pyroxene, and in many places this alteration is complete, so that there now remains only a mass of chloritic or serpentinous material. The feldspar has suffered less, yet the changes are advanced. Opaque masses of brown iron oxide appear to represent original grains or crystals of pyrite or chalcopyrite. These changes have resulted in the production of chloritic and possibly serpentinous material, calcite, quartz, and delessite. In places zeolites as thomsonite have been produced, but they are comparatively rare in the Nizina district and the region to the west, although they are abundant in amygdaloids of the White River region.

Changes of the kind mentioned are usually considered to be accomplished through the agency of circulating water. Chemical changes in the minerals of the basalts were made possible by the presence of water and the substances carried in solution. By the same means copper minerals were taken into solution and redeposited under favorable conditions. It is a noteworthy fact that the Wrangell Mountain region has been one of volcanic activity since Carboniferous time at least, and, although it has not been possible to establish a direct relation between the copper deposits and any igneous rocks of later age than the Nikolai greenstone, it is not unreasonable to suppose that the presence of heated rocks in the near vicinity may have had an important influence in promoting circulation in the greenstone and particularly in increasing the solvent power of the circulating water.

As to the manner of deposition, it is believed that the copper taken into solution by circulating water was carried into trunk channels and deposited there when the conditions were favorable. Speculations as to the exact chemical changes that took place are of very doubtful value with the present knowledge of the facts and will not be attempted. Most frequently deposition took place in the greenstone formation, but at times the copper-bearing waters passed outside the greenstone and into the overlying limestone before giving up their mineral load. As a rule, the ore bodies were not formed by the deposition of copper minerals in open cavities, although openings sufficient to permit a circulation of water were necessarily present. Most of the ore is a replacement of the country rock itself by copper sulphides. The replacement of greenstone is more nearly complete adjacent to the openings through which water passed and grows less and less as the distance from the openings increases. On the other hand, most of the limestone ores show a complete replacement of the limestone without any outside zone of disseminated sulphides.

Examination with the microscope has shown that bornite and chalcopyrite are usually associated in the greenstone deposits, even in bornite ores that show no chalcopyrite to the unaided eye. This fact, together with the manner in which chalcopyrite is scattered through the bornite, might be taken as presumptive evidence that the bornite was derived from chalcopyrite and is a secondary enrichment. This fact alone does not amount to proof, but the seeming increase in chalcopyrite as depth is gained in some of the bornite-chalcopyrite veins, such as the Nikolai vein, lends some weight to the presumption. The presence of native copper associated with chalcocite and bornite also points to the same conclusion, since native copper is usually regarded as of secondary origin. On the other hand, no evidence was found in the chalcocite deposits in limestone, such as that of the Bonanza mine, to indicate that the ore body has ever been anything other than what it is at present. The copper sulphide appears to have been deposited as such, and a careful examination of the ore has failed to discover the presence of other minerals than those produced by alteration of the chalcocite. It is doubtful if secondary enriched ores could form under the conditions now prevailing at the Bonanza mine, since all openings such as are due to joints and other fractures are filled with ice, as is also the loose talus material below the mine on both sides of the ridge. Furthermore, the breaking down of the ore and of the limestone inclosing the ore body under the climatic conditions of this region proceeds faster than oxidation. The exposed ore on the ridge and loose broken-down ore on the talus slopes show only a thin film of oxidized material on the surface. Yet thin veins of chalcocite in the limestone and even large masses of chalcocite have been almost completely altered to azurite, which shows that oxidation has taken place either under present conditions or, more probably, under earlier and more favorable conditions, possibly before the late ice advance.

The ore of the Westover claim, on Dan Creek, is an intimate mixture of chalcocite and bornite in silicified limestone along a fracture zone. The copper and copper-iron sulphides are disseminated through the rock in small grains and in veinlets cutting the rock. Most of the disseminated grains are chalcocite, but the veinlets and the larger irregular masses are a mixture of chalcocite and bornite. The veinlets are later than the quartz inclosing them and possibly later than the disseminated grains in the quartz, yet the minerals of the veinlets appear to be contemporaneous. These examples show how unsatisfactory is the evidence concerning the nature of the deposits, but they have some importance in that they do not promise greater richness in copper as the ores are followed below the surface. This point is emphasized because of the belief on the part of many prospectors in the Chitina region that the deposits will grow richer as they are more fully developed. The contrary is more likely to be true, for although they may continue with their present richness they are more apt to grow poorer than to grow richer.

DESCRIPTION OF PROPERTIES.

PRINCIPAL GROUPS.

The better-known copper properties of the Nizina district may be divided into three groups—first, the group in the vicinity of Bonanza Peak, including the Bonanza mine, the Jumbo, the Erie, and the Independence claims, together with the properties known as the Marvellous and Bonanza extension claims; second, the Nikolai Creek group; and, third, the group that includes the Westover claim and other neighboring claims north of Dan Creek. Many other claims have been staked, particularly along the limestone-greenstone contact, but there has been little development work done on them and they contribute little to our knowledge of the copper deposits of the district.

BONANZA MINE.

The Bonanza mine is the most valuable[a] copper property now known in the Copper River region. It is situated on the east side of Kennicott Glacier, at the head of Bonanza Creek, and is the property of the Kennicott Mines Company. Bonanza Creek proper and its western fork head in a glacial cirque basin on the west side of the high divide between Kennicott Glacier and McCarthy Creek. Its two forks include the high ridge on which the copper deposit is situated. The stream is about 3 miles long and flows in a southwesterly direction to the Kennicott Glacier. A post-office called Kennicott has been established at the mouth of National Creek, half a mile south of the mouth of Bonanza Creek and 4 miles from the mine, and the company's main camp and office are located at that place. A wagon road leads from the mouth of National Creek to a point about 500 feet below the mine and another follows the edge of the glacier south to McCarthy Creek. An aerial tram with a capacity of 100 tons per day has been constructed and loading and delivery stations have been built, so that the mine is now practically ready to begin the production of ore, although the storage bunkers are not completed and no ore can be shipped till the railroad reaches Kennicott.

An examination of the geologic map (Pl. III, in pocket) will make clear the general geologic conditions. South of National Creek the high ridge between the glacier and McCarthy Creek consists of black Kennicott shale intruded by large masses of light-gray porphyry. The Jurassic shales and intrusives are separated by an unconformity and probably also by a fault from the greenstone and the overlying Chitistone limestone on the north. North of National Creek the greenstone and limestone appear. The strike of the limestone is northwest and southeast, and its dip averages between 25° and 35° NE. It therefore cuts diagonally across the main ridge from McCarthy Creek to the glacier. Still farther northeast the Triassic shales overlying the limestone appear, but are not of any importance in connection with the copper.

The Bonanza mine is situated on a spur that runs out to the southwest between the forks of Bonanza Creek from the main ridge. This spur is crossed by the limestone-greenstone contact at a point about one-third of a mile from the main ridge. Where the boundary crosses the crest of this spur it has an elevation of 6,000 feet above sea level or 4,000 feet above the point at the mouth of National Creek where the tramway will deliver ore. On the northeast the spur

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[a] Since the Bonanza mine was visited in 1907 much work has been done toward surface development and equipment of the mine for shipping ore, but work on the ore body itself has not been such as to add greatly to the knowledge of the deposit. For this reason the description here given is based largely on the previous description published in Bull. U. S. Geol. Survey No. 374.

WEST SIDE OF RIDGE AT BONANZA MINE.

The richest ore exposed on the surface is on the top and face of the ridge between the points indicated by arrows. See page 85.

rises rapidly till 1,000 feet in elevation is gained, but on the southwest its crest is almost horizontal for a distance of about one-third of a mile, beyond which it slopes away steeply to the forks of Bonanza Creek (Pl. XII).

The greenstone immediately below the ore body is variable in texture and general appearance. Part of it is amygdaloidal; porphyritic phases are also present. Amygdules are not confined to the top of the flows but are present throughout from bottom to top. In some places they have been dissolved out on exposed surfaces, leaving a vesicular rock that looks like a recent lava. A bed of red and green shale having a thickness of about 5 feet intervenes between the greenstone and the overlying limestone. This shale forms a narrow northward-sloping bench for a short distance along the northwest side of the ridge, but is everywhere covered with talus and is found only when the débris has been cleared away. The bench is clearly indicated by the snow banks in Plate XII. The base of the limestone consists of not less than 40 feet of coarse gray, slightly argillaceous rock, whose broken surfaces are covered in many places with flattened cylindrical bodies that immediately suggest organic material of some kind. Several specimens of these bodies were submitted to Dr. T. W. Stanton, who says that they are probably corals but are too obscure for identification. Over this basal limestone is a bed a few feet thick of impure shaly limestone, and this in turn is overlain by dark and light-gray massive beds which carry the ore bodies. The limestone dip at the mine is slightly variable but averages about 22° NE.

The limestone is broken by numerous faults and fracture planes, the most prominent of which are nearly perpendicular and range in strike from N. 40° E. to N. 70° E. A minor set of fault planes with about the same strike dips steeply to the west. Another set runs in a northwesterly direction, and in several places striations on slickensided surfaces or clay seams show that the movement was horizontal. Fault planes with low dips, some of them nearly horizontal, are also present. None of the faults observed give evidence of much displacement, but together with the numerous joints they afforded an opportunity for mineral-bearing waters to enter the limestone. The principal fault planes—those running from northeast to southwest—form what may be described as a sheeted zone in the limestone that was traced north-northeast from the Bonanza mine for 1½ miles. This zone has a width of 50 or 60 feet and extends through the shale bed into the greenstone below, but is less noticeable in the greenstone than in the limestone. A vertical displacement of 2 feet occurs in the limestone-greenstone contact along one of the fault planes in the shear zone and is the maximum displacement observed.

The copper ore is chalcocite. Considerable azurite has been formed by oxidation of the chalcocite, and covellite is reported also. Covellite was not found in the specimens of ore collected from the Bonanza mine by the writers, but good specimens of covellite were collected from the Marvellous claim half a mile to the northeast, and its occurrence at the Bonanza is not questioned. The chalcocite is in veins or tabular masses of solid ore up to 5 or 6 feet in thickness, in large irregularly shaped bodies, and in stockworks in the brecciated limestone. Two principal veins of chalcocite are seen on the surface. They stand almost perpendicularly, 12 to 15 feet apart, and strike N. 41° E., forming the comb of the sharp ridge but crossing it at a slight angle, as the ridge at this place has a more nearly north-south direction than the veins. On the surface the veins do not extend down into the lower impure part of the limestone but end abruptly on reaching it. In places the precipitous northwest face of the ridge is plastered over with masses of solid chalcocite for a distance of 50 or 60 feet vertically below the top.

Azurite appears on the surface of the chalcocite and also as a lining of small vugs in the chalcocite, but it is present chiefly as thin veins, that form a network in the limestone and are doubtless due to the alteration of original chalcocite veins, for some of the azurite has an inner core of chalcocite. Azurite is more conspicuous than chalcocite in the surface network of veins in the northern 150 feet of the ore body, but chalcocite forms the great mass of the remainder. The ore bodies formed along the northeast-southwest faults of the northern part of the deposit are not the direct continuation of the large chalcocite veins at the south, but lie in nearly parallel veins which cut the ridge at a greater angle, their strike being about N. 60° to 70° E. The very rich ore can be traced on the surface for a distance of about 250 feet. It ends abruptly on the south in a nearly vertical limestone wall, but on the north gives place to the lower-grade ores, consisting of small veins of azurite and chalcocite with scattered masses of chalcocite, some of them weighing several tons. This lower-grade ore shows on the surface for a distance of at least 150 feet northeast from the high-grade ores, and small scattered azurite veins extend still farther in that direction. The ore, as it shows on the surface, therefore, extends northeast and southwest along the strike for a distance of 400 feet. The thickness, however, is more indefinite, but the very rich ore, with its included limestone, as seen at the surface, has a width of approximately 25 feet, although the thickness of ore sufficiently rich to be mined may be greater.

A little chalcocite and less bornite are found in some of the shearing planes in the greenstone, but they do not extend far into the greenstone. The quantity is small and inconspicuous and might readily pass unobserved. A small amount of epidote is associated with it in places. The main shear zone in the greenstone cuts an older set of quartz-epidote veins whose direction is about north-northwest. These veins do not intersect the limestone. They reach a maximum thick-

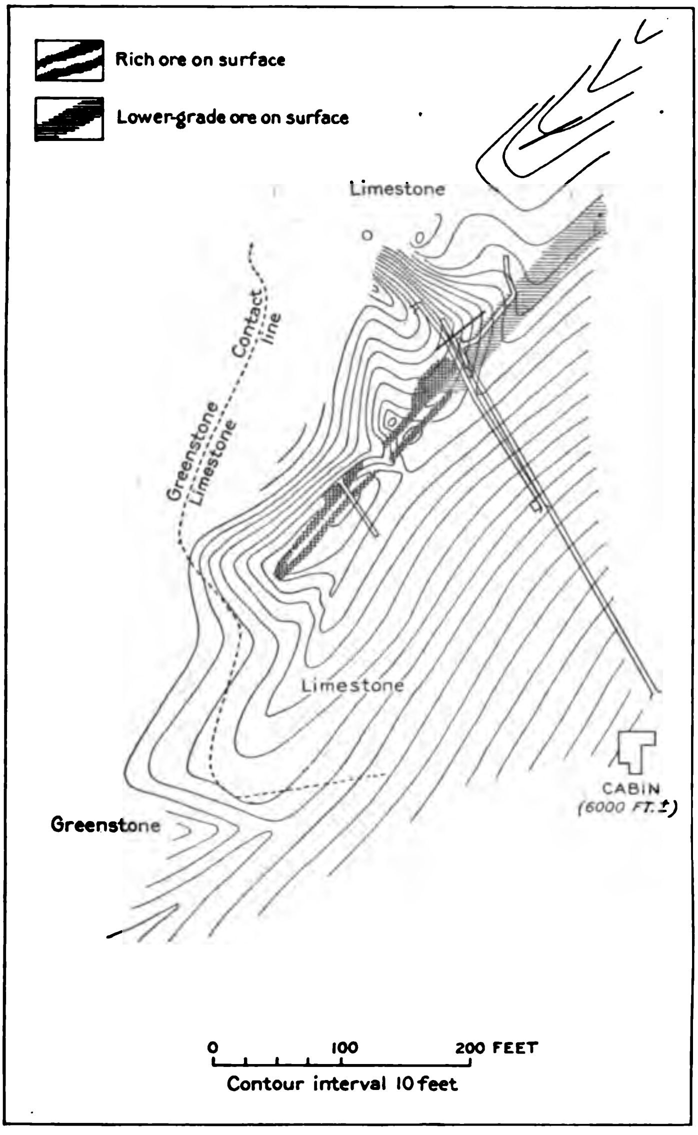

FIGURE 5.—Sketch map of the area near the Bonanza mine, showing the limestone-greenstone contact, the location of the richer ores on the surface, and the tunnels.

ness of 1 foot and carry small amounts of chalcocite, bornite, and native copper.

When the Bonanza mine was visited in 1907 two crosscuts (fig. 5) had been driven in the ore body in a direction N. 33° W. They are therefore not exactly perpendicular to it. The longer tunnel starts on the east side of the ridge and 75 feet below its top; it is 180 feet in length and extends through to the west side of the ridge. The richest ore, consisting of large masses of chalcocite with some included limestone, is encountered at a distance of 90 feet from the tunnel's mouth and continues for a distance of 21½ feet as measured in the roof. There are smaller bodies of chalcocite, however, for a distance of 10 or 15 feet on either side of the main ore body. About 115 feet from the entrance to the tunnel a winze 33 feet deep was sunk in the ore, and from the bottom a drift zigzags northward approximately 110 feet.

In 1909 a new tunnel had been driven below this longer tunnel from the southeast side of the ridge and connected by a raise with the winze. The new tunnel is 78 feet below the upper one and parallel with it. In July, 1909, it had been driven 45 feet beyond

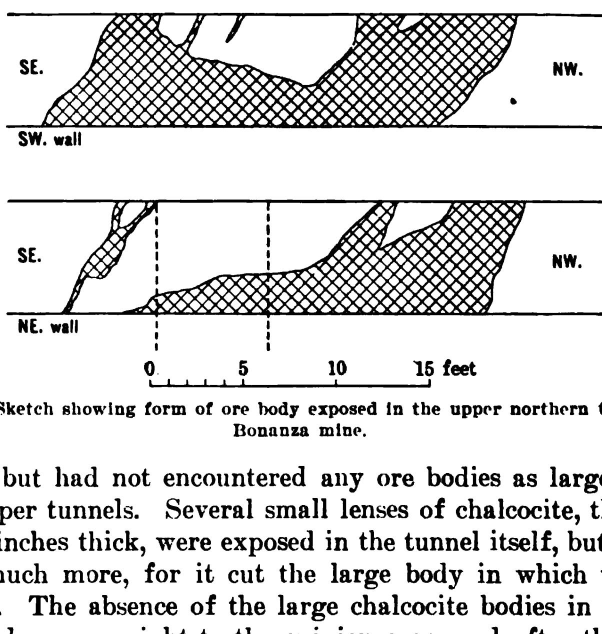

FIGURE 6.—Sketch showing form of ore body exposed in the upper northern tunnel at the Bonanza mine.

the raise but had not encountered any ore bodies as large as those of the upper tunnels. Several small lenses of chalcocite, the largest about 18 inches thick, were exposed in the tunnel itself, but the raise showed much more, for it cut the large body in which the winze was sunk. The absence of the large chalcocite bodies in the lower tunnel adds some weight to the opinion expressed after the visit of 1907 that the ore would probably not extend into the basal impure limestone beds.

About 120 feet southwest of this tunnel is a parallel tunnel driven from the west side of the ridge and 50 feet lower than the little saddle above it on the north. This tunnel starts in a face of solid chalcocite and extends S. 33° E. for 50 feet. The ore, which is chalcocite with a small amount of azurite, is exposed for 34 feet along the tunnel, but is interrupted by horses of limestone. The remainder of the tunnel shows limestone cut by small azurite veins and in places containing a small amount of chalcocite.

A better conception of the form of the ore bodies can be obtained by an examination of figures 5, 6, and 7 than can be given in a written description. The two main parallel surface veins afford only an imperfect idea of the deposit. Those two veins represent a total replacement of limestone along minor zones, where shearing was most intense. The two tunnels show that not only is the limestone replaced along the main shear zone but that mineralized waters followed minor fracture planes also, and thus yielded the low-lying ore bodies and great irregular masses seen underground. Between and around the large masses of chalcocite the limestone was shattered and filled with many small veins of ore, which formed a stockwork that is most noticeable in the winze tunnel and on the surface northeast of the main ore body. As a rule, the brittle chalcocite is very little fractured. The limestone, on the other hand, is greatly shattered and is filled with thin veins of calcite which are older than

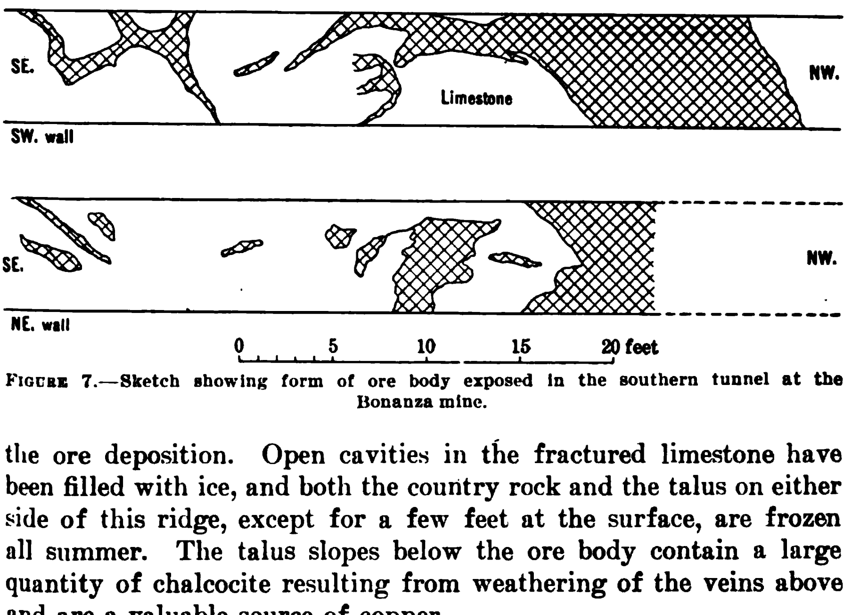

FIGURE 7.—Sketch showing form of ore body exposed in the southern tunnel at the Bonanza mine.

the ore deposition. Open cavities in the fractured limestone have been filled with ice, and both the country rock and the talus on either side of this ridge, except for a few feet at the surface, are frozen all summer. The talus slopes below the ore body contain a large quantity of chalcocite resulting from weathering of the veins above and are a valuable source of copper.

It is a suggestive fact that, although the main shear zone of the Bonanza mine extends from the limestone through the thin shale bed into the greenstone below, the large chalcocite bodies, so far as can be determined on the surface, end abruptly at the top of the impure shaly beds forming the lower 50 or 60 feet of the limestone. Copper minerals are associated with the shear zone in the greenstone, but only in small amount. Apparently the impure thin-bedded part of the limestone was a less favorable place for deposition than the purer massive beds above. This fact has a practical bearing on the quantity of ore present, for it is evident that if the same condition continues underground it limits the downward extension of chalcocite in the limestone. The continuation of the ore body to the northeast will probably be limited chiefly by the continuation of favorable conditions for deposition in the shear zone in that direction. The exact conditions which determined the deposition of the Bonanza ore body are not known; possibly it was the presence of a shear zone favorable to circulation; but its occurrence, together with that of the Jumbo and the Erie chalcocite bodies to the northwest, next to be described, indicates that favorable conditions for deposition have been established in more than one place and offer encouragement for seeking other chalcocite bodies at the base of the Chitistone limestone.

JUMBO CLAIM.

From the Bonanza mine the Chitistone limestone continues northwestward in a succession of lofty cliffs as far as Kennicott Glacier. The base of these cliffs is at the greenstone contact and in many places contains veinlets and stringers of azurite or chalcocite. In at least two places the quantity of these two minerals, especially of the chalcocite, is so great as to make the deposits of commercial importance.

The ore body of the Jumbo claim is 4,600 feet northwest of the Bonanza, at the head of Jumbo Creek, and is located in limestone just above the greenstone-limestone contact on a small southwestward projecting spur or angle of the limestone cliff. South of it and nearly 200 feet below is the glacier in which Jumbo Creek heads and which must be crossed to reach the ore body. The Jumbo and Bonanza ore bodies are at practically the same elevation above sea level, approximately 6,000 feet.

The limestone at the Jumbo is made up near the base of slightly cherty beds ranging in thickness from 8 to 12 inches. The strike is N. 65° W., the dip 35° N. A tunnel 12 feet long was started on the south face of the ridge, 10 feet above the greenstone. The limestone is jointed or cut by minor faults parallel to the bedding and is crossed by veins of calcite from 1 to 2 inches thick. Thin veins of chalcocite and azurite accompany them and fill some of the fractures. Seven feet above the tunnel mouth is the east end of a large chalcocite mass which is well exposed on the axis of the ridge. As indicated on the surface, this body of ore is a mass of solid chalcocite 30 feet long, 6 feet by 4 feet 6 inches at the west end, and tapering to a diameter of 1 foot at the east end. It appears to be a rudely lenticular or possibly a conical body, but has irregularly shaped protuberances, as may be seen at the west end, where the steep west face or slope of the spur gives a cross section of the ore body. (See fig. 8.)

A little way east of the Jumbo tunnel is a second tunnel in limestone a short distance above the greenstone. The tunnel runs nearly north or slightly to the northeast in limestone that strikes N. 65° W. and dips 25° N. In the tunnel, which is 12 feet long, the limestone is crushed and jointed. Small veins of calcite and azurite up to 2½ inches in thickness fill joint cracks, especially a set of perpendicular minor faults or slip planes running N. 70° W. No chalcocite is exposed in this tunnel, but it is believed that the azurite indicates its former presence. Fifty feet below the tunnel a lenticular vein of chalcocite 3 inches thick at its widest part and 3 feet long was found in the limestone.

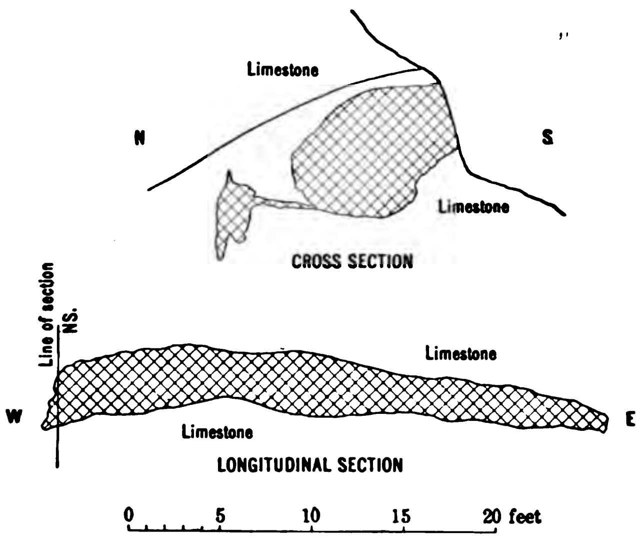

FIGURE 8.—Sketch of the ore body at the Jumbo claim.

ERIE CLAIM.

The Erie claim is the property of the Kennicott Mines Company and is situated on a steep mountain slope near the east side of Kennicott Glacier, 3¾ miles north of Kennicott, at the mouth of National Creek. The discovery point is a little more than 1,000 feet above the nearest point of the glacier and is at the limestone-greenstone contact, which here strikes N. 78° W. and dips 38° N. Between the limestone and the greenstone is a bed of greenish shale of variable thickness, but ranging from 12 to 18 inches. There is also a very thin bed of shale not more than 1 inch thick in the limestone 8 inches above the base. There appears to have been movement between the limestone and the greenstone along their plane of contact, and they were further disturbed by small faults cutting across the contact at high angles to the bedding in such a way that at one place a wedge of greenstone projects into the limestone. The larger shale bed contains many nodules of chalcopyrite from one-half inch to 2 inches in diameter, and with the chalcopyrite there is associated more or less bornite in the larger nodules. Abundant scales of azurite are scattered through the shale. No development work has been done on this claim further than to clear away the débris and make an open cut along the contact so as to expose the copper-bearing shale.

INDEPENDENCE CLAIMS.

The Independence group of claims, belonging to the Kennicott Mines Company, is on the east side of the divide that separates the head of Bonanza Creek from McCarthy Creek and is from 900 to 1,000 feet lower than the saddle where the limestone-greenstone contact crosses the ridge. The copper minerals occur in small veins that contain considerable calcite and belong to a sheeted zone striking N. 38° E., thus crossing the contact almost at right angles. This zone passes from the greenstone into the limestone and has its greatest width (about 50 feet) at the contact. The ore is found in the greenstone only and consists essentially of chalcocite, which fills fractures and is disseminated through the greenstone. It is later than the calcite filling of the sheeted zone and gradually disappears with increasing distance from the zone of mineralization. The main shear zone intersects a system of quartz-epidote veins striking N. 78° E. and carrying a small amount of bornite. There is a marked similarity between the occurrence of copper sulphides in the greenstone at this locality and at the Bonanza mine, but there is no chalcocite body in the limestone of the Independence claim.

MARVELLOUS AND BONANZA EXTENSION CLAIMS.

The shear zone in which the Bonanza ore was deposited extends in a direction about N. 30° E. from the Bonanza mine for a distance of more than a mile. It crosses the saddle between Bonanza Creek and the glacier on the north and extends to the high point of the ridge running northeast from Bonanza Peak. It was not traced beyond that point. There is no evidence of displacement, but there is a shear zone of indefinite width made up of innumerable small parallel fractures filled with calcite and crossed by minor fault planes. These fault planes are believed to have had an important and perhaps a controlling influence in the deposition of copper.

All the Bonanza fault northeast of the Bonanza property is owned by the Mother Lode Copper Mines Company and the Houghton Alaska Exploration Company. The principal exposures of copper minerals are on the Marvellous claim, where a number of short tunnels have been driven. The Marvellous claim is on the north side of the glacier east of Bonanza Peak and is about 2,800 feet above the valley of McCarthy Creek.

At the south tunnel of the Marvellous the limestone is cut by numerous closely spaced parallel joint or shear planes, many of which are filled with calcite and are conspicuous because they are lighter in color than the surrounding limestone. They strike N. 70° E. and dip 70° to 80° N. The tunnel is 15 feet under cover and exposes a vein of chalcocite from 3 to 6 inches wide striking N. 60° W. About 30 feet north of the tunnel's mouth and 25 feet lower is a vein of chalcocite in calcite that reaches a maximum thickness of 9 inches. It strikes N. 60° E. and dips 60° to 65° W. The vein is in a well-defined fault plane and can be traced for nearly 200 feet from the tunnel's mouth. In places it pinches to a thickness of 1 inch and carries no ore. Fine specimens of covellite in chalcocite were obtained from this locality. There is a second parallel vein 12 feet to the north, but it is not so long.

The main tunnel of the Marvellous is 300 feet northeast of the south tunnel and runs 100 feet S. 85° W. in dark-gray limestone. The vein is a stockwork of small calcite veins, with chalcocite and azurite in crushed limestone. About 20 feet from the face is a crosscut 9 feet long where there is a vertical fissure in the limestone striking N. 25° E. The fissure is filled with calcite and carries chalcocite and azurite. It has a thickness of 6 inches. The limestone is much discolored by iron oxide. Above the tunnel is a large mass of azurite formed by the oxidation of chalcocite whose downward extension the tunnel was expected to strike.

A third tunnel, called the north tunnel, was started on the Marvellous claim 200 feet northeast of the main tunnel and 100 feet above it. The copper minerals at this exposure occur along bedding planes of the limestone, which here strikes N. 40° W. and dips 35° E., and along fault planes that cross the bedding. The faults strike N. 10° W. and dip 44° E.

NIKOLAI CLAIM.

The Nikolai claim is located near the head of Nikolai Creek, 3¾ miles northeast of the junction of Nikolai and McCarthy creeks and 2,150 feet above it. The exposed ore body is situated near the top of the greenstone formation, about 150 feet below the base of the limestone, and is associated with a fault which cuts the limestone-greenstone contact at this place. It is composed mainly of chalcopyrite and bornite stained with oxidation products.

An examination of figure 9 will show the relation of the ore body to the associated formations. It will be seen that the limestone and greenstone beds, which here strike N. 60° W. and dip 30° NE., are cut by a fault running N. 50° E. and dipping vertically or high southeast. This fault makes an offset of 300 feet in the limestone-greenstone contact and has produced a vertical displacement of the beds amounting to 150 feet. The course that it follows in the limestone or in the greenstone at a distance from the contact is difficult limestone and the Nikolai greenstone, but the ore body is, so far as now exposed, in the limestone. Most of the limestone-greenstone contact in the upper end of Bowlder Creek valley is covered by talus from the high limestone cliffs that form the valley walls, yet in a few places, of which this locality is one, the contact is exposed for short distances. The strike of the limestone beds and the greenstone flows is here N. 15° W. and the dip is 15° E. In half a dozen or more places within the valley appear small faults cutting across the contact of the two formations and causing displacements that in several instances amount to a hundred feet or more. One or two such displacements took place a short distance south of the Westover ore body, thus bringing the greenstone at the outcrop to a higher position with reference to its nearest exposures on the south than it would have otherwise had. Both limestone and greenstone near the ore body are broken by many joints and crossed by slip planes of little displacement. Locally the rocks are much shattered and break down in small fragments. One of the most prominent of the fractures has an important relation to the ore body. It is a fault, probably of small displacement, whose contact surfaces are warped surfaces rather than planes, so that the trace of the fault on the ledge is a curved line sloping from right to left as one looks at it. This fault strikes west-northwest and dips 45° NNE. The ore body lies on the north or upper side of the fault, but is not fully exposed because the talus has been but partly cleared away from its base and the actual contact of limestone and greenstone is not in sight. Copper ore is exposed along the face of the limestone cliff at the top of the talus slope for a distance of 35 feet horizontally and at the south end of the ore body for a distance of about 10 feet vertically. The south end of the ore body is rich massive bornite and chalcocite ore, which is sharply cut off from the limestone south of it by the fault and has been formed by an almost complete replacement of limestone by the copper sulphides. On following the ore body north the richness of the ore rapidly decreases, till finally bornite disappears and only silicified limestone is seen.

The copper-bearing solutions followed all the available openings in the limestone—joints, bedding planes, and faults—and the richest ore is near such openings, for here the lime carbonate was wholly replaced by copper sulphides. The amount of replacement varies inversely as the distance from these openings till, within a few inches or a foot, the grains and tiny veinlets of bornite can no longer be seen in the limestone. Where the limestone was greatly shattered the opportunity for replacement was greater; but in the more massive parts of the beds it took place sparingly, if at all.

The sharply defined contact of ore and limestone at the fault on the south suggests that the displacement is later than the ore deposition. If this is the case, the present exposure does not show a complete section of the original ore body and further prospecting may reveal the displaced part.

OTHER PROSPECTS.

There has probably been more prospecting for copper in the Nizina district than in any other part of Chitina Valley except the vicinity of Kotsina River. Prospecting was stimulated by the discovery of such deposits as the Bonanza, the Jumbo, the Nikolai, and other claims and by the presence of a greater number of prospectors. The limestone-greenstone contact has been examined with care wherever it is accessible, and most of it has been staked. Most of the copper found is of the class of disseminated sulphides in greenstone. Examples of this class are found in the Donohoe prospects in the greenstone on the east side of McCarthy Creek and the prospects of the Alaska United Copper Exploration Company on the west side of Bowlder Creek, opposite the Westover claim, and on the east side of Bowlder Creek north of Dan Creek. The copper sulphides of the last-named locality occur along joint or fault planes, some of which are nearly parallel with the major strike fault of the Dan Creek valley and some cross these at large angles. In 1909 a tunnel was being driven on the property about one-fourth of a mile east of Bowlder Creek and 275 feet below the limestone-greenstone contact to cut a fissure carrying copper minerals that was exposed 175 feet higher to the north. A belt of greenstone with disseminated copper sulphides is found at about this distance below the limestone and extends east along the north side of Dan Creek valley. It carries small amounts of bornite and chalcopyrite, and in places a little native copper is present. The native copper is believed to be a secondary alteration product derived from the sulphide. Bowlders of greenstone carrying native copper are not unusual in the gravels of Dan Creek. Not much work has been done on the native copper-bearing greenstone, and the quantity of copper there is not yet determined. The principal prospects of this kind are on the upper part of Dan Creek and are the property of the Dan Creek Gold and Copper Company.

A small deposit of copper carbonates, malachite, and azurite is found in the limestone only a few feet above the limestone-greenstone contact south of Chitistone River, a mile east of the Nizina River valley. The copper minerals were deposited in a crushed and faulted part of the limestone and the whole is much stained with iron oxide. Two short prospecting tunnels were driven in the limestone by the Houghton Alaska Exploration Company, to whom the prospect belongs.

GOLD.

PRODUCTION.

All the gold produced in the Chitina Valley has come from the placers of Dan, Chititu, and Young creeks. Chititu Creek is the principal producer, and after it comes Dan Creek. Young Creek has had only a small output up to the present time and may almost be disregarded as a contributor in past years, but with lower freight rates and cheapened cost of production it may become of greater importance in the future. The total gold production of Chititu and Dan creeks from 1903 to 1909, inclusive, may be estimated with a considerable degree of accuracy as between $450,000 and $500,000, or an average of about $65,000 a year. There is good reason to believe that with the installation of new equipment on the completion of the railroad this yearly average will be much increased.

SOURCE OF THE GOLD.

It may be said with certainty that the source of the placer gold of Dan, Chititu, and Young creeks is in the black shales of the Kennicott formation. This is clearly shown by the distribution of the gold itself. All the tributaries that flow into Dan and Copper creeks from the northeast, including Dan Creek above the mouth of Copper Creek, lie within the limestone-greenstone area and carry no gold. All the tributaries that flow into Dan and Copper creeks from the southwest head in the shale area and all carry gold. All the gravel deposits of Dan and Copper creeks except a part of the bench and stream gravels on lower Dan Creek are derived from sources within the drainage basin of these streams. No foreign material was found, and there is almost no possibility that any could be present, for the whole basin is surrounded by steep walls which probably never were below the surface of the ice fields during the time of greatest glaciation.

All the tributaries of Chititu Creek originate within the black shale area and all carry gold, but here, as on Young Creek, part of the gravels are of foreign origin brought in by glacial transportation. Rex Creek is the one exception to this statement, for its gravels, save in the lower mile of its course, are all derived from within its own drainage basin. The gravels of the upper Rex Creek valley are derived from the black-shale area and carry gold. No evidence was obtained to indicate any other source for the gold of Chititu and Dan creeks than the shales lying between Dan and Young creeks, although all the copper and probably all or nearly all the silver of Chititu Creek came from an outside source.

Many small quartz veins carrying pyrite and native gold have been found in the black Kennicott shales between Copper and Rex creeks.

They range in thickness from less than an inch to several inches and are believed to have a close relation to the porphyritic intrusions in the shales. Molybdenite is present and stibnite is also reported from these veins. The placer gravels contain, besides the metals gold, silver, and copper, such heavy minerals as galena, cinnabar, barite, pyrite, and possibly marcasite. Native lead with a white coating, thought to be cerusite, was found in the sluice boxes on Chititu Creek, but may have been introduced by white men or natives, for bullets and shot are common. Not all of these minerals have been found in place in the rock, but it is probable that they also are associated with the quartz veins and porphyry intrusions. Thin veins no thicker than a sheet of paper are common in joint planes of the hard argillite bowlders in the stream gravels. They contain quartz, pyrite, and in places free gold. A thin vein less than one-fourth of an inch thick was found in a porphyry dike on the upper part of Rex Creek, which consisted of quartz with molybdenite and pyrite and assayed 0.18 ounce gold and 12.80 ounces silver to the ton. The dike rock near the vein, although seemingly little altered, contained pyrite and showed a trace of both gold and silver. There is thus good evidence for the source of the gold aside from that furnished by its distribution in the gravels.

The gold in the stream gravels is in part a concentration from the bench gravels through which the streams have cut their channels and in part a concentration from the products of weathering derived directly from the shales and the auriferous veins. Probably the greater part is a reconcentration from the older deposits. Extensive accumulations of high bench gravels are present on both Dan and Chititu creeks. They are best developed on the lower parts of the streams but extend into some of the tributary valleys. The bench gravels of Dan Creek extend west from the neighborhood of Copper Creek and around to the west slope of Williams Peak,[a] where they reach an elevation of over 1,200 feet above the flats of Nizina River. The bench gravels of Chititu Creek reach an elevation as great as or greater than those of Dan Creek. In both places they represent a filling in old valleys through which the present streams have cut their channels and in so doing have reconcentrated a great volume of older deposits, derived partly from the upper Nizina Valley and the region east of the heads of White and Young creeks but chiefly from the drainage basin of Dan and Chititu creeks. When the bench gravels were laid down the two great ice streams that came down the Nizina and Chitina valleys were still in existence, although on the retreat. They formed the barrier behind which it was possible for such deposits to accumulate

[a] Williams Peak is named in honor of John M. Williams, a pioneer prospector of the Nizina district, who was killed in a snowslide on Bonanza Creek on April 7, 1909.

and brought to the bench gravels that part of them which is foreign to Dan and Chititu creeks. It is impossible to say what proportion of the gravels consists of foreign material, but it is believed to be the smaller part. Some of the bench gravels carry gold in sufficient quantity to be of commercial importance, as has been proved at a number of places. A reconcentration of such deposits accounts in part for the greater richness of the stream gravels. The process that brought about this concentration is exactly the same in principle as that carried on in the miners' sluice boxes on a much smaller scale but in a much shorter time. This concentration is probably slower at present than it was before the streams had cut through the deep gravel accumulations and intrenched themselves in the underlying hard rock, but it still goes on, for erosion of the bench gravels has not ended.

PLACER DEPOSITS.

DAN CREEK.

Dan and Copper creeks may well be regarded as one stream in spite of whatever accident or design resulted in their having different names and of the fact that the upper part of Dan Creek sometimes carries as much or more water than Copper Creek. A reference to the geologic map (Pl. III, in pocket) will show that the two streams follow closely the course of the fault that gave the older greenstone and the limestone on the north their relative elevation above the base of the Kennicott formation. With unimportant exceptions, the north side of the Dan and Copper creek valleys is in limestone and greenstone, the south side in shales of the Kennicott formation. Most of Copper Creek is in a broad glaciated valley, but at a point nearly 1 mile above its mouth the creek enters a narrow rock-walled canyon that opens slightly below Copper Creek yet extends down Dan Creek nearly a mile. Dan Creek valley below the canyon is narrow and shut in by steep mountains as far as the flats of Nizina River.

During the ice invasion the Copper Creek valley was swept clear of whatever unconsolidated deposits may have accumulated, and the form of the valley was considerably modified. When the ice was retreating some glacial débris was left on the valley floor, but it is of less importance in connection with the gold placers than the accumulations of stream gravels that have been laid down since the glacier disappeared. In this respect the placers of Copper Creek are different from those of Dan Creek.

All the tributaries of Copper Creek on its south side, as Idaho, Rader, and Seattle gulches, carry gold, but most of the output of the creek comes from near the mouth of Rader Gulch. Part of the gold is from the gulch itself and part is from Copper Creek, just below the gulch. The gravels are all shallow. Those in the mouths of the gulches are composed almost entirely of shale, chiefly from the Kennicott formation but also in part from the McCarthy shale. They occupy narrow gulches and accumulate so rapidly that the streams have difficulty in removing them. The gravel deposits of Rader Gulch are of this character. They consist of loose shale fragments and occupy only a few hundred feet of the lower end of the gulch, for above them the grade is so high and the channel so narrow that the water removes loose material rapidly. The gravels of the main stream contain material from all the formations within the drainage basin. At Rader Gulch they form a narrow flood-plain area between the mountain slope on the southwest and a low ridge on the northeast. They contain considerable coarse material mingled with blocks and bowlders of glacial origin and much fine material derived from the shales. The gold is not a concentration from older, lower-grade deposits but is derived directly by weathering and by stream concentration of the products of weathering. The source of most of the gold is clearly indicated by its position in the gravels at and just below the mouth of Rader Gulch and the presence of workable gravels on the lower part of Rader Gulch.

Idaho and Seattle gulches resemble Rader Gulch in their form and the character of their gravel deposits, but they have not been found to carry as much gold.

Copper Creek is difficult to reach with supplies except in winter, for the canyon makes necessary a high climb of more than 1,000 feet around the side of Williams Peak. Men on foot, however, can follow the creek. Logs have been placed across the stream in the canyon and make it possible to avoid bad places. Mining on Copper Creek is done with pick and shovel. There is a small supply of timber for firewood and for sluice boxes, but it would not be adequate for extensive mining operations. Good timber for lumber can be secured along Nizina River, but the expense of carrying it to Copper Creek under present conditions, except in winter, would be great.

The gold of Dan Creek has a less simple history than that of Copper Creek. It is in part a reconcentration from older gold-bearing bench gravels and in part, like that of Copper Creek, a concentration from the products of later erosion. Old high-bench gravels are found on both sides of Dan Creek, especially on the lower part, but near the west end of the canyon they lose their prominence and disappear altogether at or below the mouth of Copper Creek. Dan Creek has cut its present channel down through this great accumulation of glacial and stream deposits and into the shales beneath. The stream gravels consist of greenstone, limestone, and shale. They form between rock walls a narrow flood plain overgrown with timber and in many places of less width than a placer claim. A large part of the gravels consists of bowlders ranging from cobbles to masses several feet in diameter. Most of them, however, are not too large to be moved by hand. All the fragments are rounded. They were deposited by a rapidly flowing current and the bedding is poor. Buried spruce logs and fragments of wood are common. The gravel and its slight covering of soil range from 8 to 12 feet in depth.

Dan Creek gold is coarse and smooth and is accompanied by silver and copper. It has been concentrated on bed rock or within the lower 2 feet of the gravel. A large proportion, however, finds its way into the cracks and crevices in the shale, so that in places a foot or more of the shale has to be removed to recover all the metal. An unusual feature of the gravels of Dan Creek is the small quantity of fine gold found in them. Very little fine gold is recovered in the sluice boxes and practically none is found in panning. Numerous prospect holes show that the gold is well distributed across the channel and have failed to discover the presence of a concentration into a defined pay streak. Beside the holes sunk on the flood plain, tunnels have been driven along bed rock at the base of the bench gravels above the present flood plain. The depth to which the creek has incised itself in the shales is not constant but is rarely less than 10 or 15 feet. Thus the base of the bench gravels or the "rim" of the channel stands well above the creek. The tunnels driven in the bench gravels show the presence of gold in sufficient amount to be of commercial importance and in several places in sufficient amount to pay for extraction under the expensive methods necessary in prospecting the gravels, but the final test of value will come when an attempt is made to extract the gold on a large scale.

An old channel formerly occupied by Dan Creek lies in the bench gravels on the south side of the present stream. It runs on the south side of the small round hill west of the mouth of Copper Creek and follows the hillside to the west, but it has not been traced definitely. Doubtless much of it has been removed by erosion. Its gravels carry gold, and an attempt has been made to exploit them in a small way, but without great success.

Dan Creek is favorably situated with reference to timber for mining purposes and has a good supply of water. It is reached without any difficulty from the Nizina, and a wagon road for hauling timber and supplies has already been built. All mining to the present time has been by the simplest methods. The one employed for several years is to undercut the bank with a stream of water and by washing away the gravel to leave the gold. Bowlders and small rocks are piled parallel with the bank and only a few feet from it. Then water controlled by dam and gates is turned in and forced against the bank, undercutting it and carrying away most of the fine gravel. The large rocks are piled back by hand and the remaining fine gravel and gold are shoveled into sluice boxes, after which bed rock is cleaned. Preparation has been made for installing a hydraulic plant on Dan Creek, and it will be put in place as soon as the railroad is completed and better facilities for carrying freight are established.

CHITITU CREEK.

Chititu Creek and its two branches, Rex and White creeks, lie wholly within the area of Kennicott sediments. These streams, like Dan Creek, have cut their present channels through the old valley filling and entrenched themselves in the black shales. The amount of this entrenchment is variable, ranging from nothing below the canyon on Chititu Creek to 60 or 70 feet on White Creek, but the increase is not uniform. It is about 30 feet at the mouth of White Creek, but is greater than that in places farther down on Chititu Creek. It decreases as Rex Creek is ascended and also on the head of White Creek. The canyon on Chititu Creek is due to the presence of a large porphyry dike in the black shales, which has protected them from rapid stream cutting and confined the water to a narrow channel. The canyon is small but marks the downstream limit of gold-bearing gravels that are now considered of commercial importance.

Above the rim of the shallow trench cut in the shales by the stream are steep banks of rudely assorted gravels. The top of the gravel bluff at Sunday Gulch is a little more than 500 feet above Chititu Creek. Half a mile downstream the top of the bluff is 750 feet above the creek, but from this point on the difference grows smaller till the bench gravels merge into the gravels of Nizina Valley a short distance below the canyon. Bench gravels are prominent on Rex Creek for a mile or more above its mouth, but they either were not deposited or have been removed from the upper end of the creek, where the unconsolidated accumulations are wholly glacial débris. A large part of the bench deposits of White Creek have been eroded away, yet they extend up the creek in conspicuous exposures for at least 2 miles.

The richest gold-producing gravels of Chititu Creek are the stream gravels; they include all of Chititu Creek above the canyon, together with a large part of Rex and White creeks. The most important parts of these creeks, viewed from the standpoint of gold production, are represented on the sketch map (fig. 10). The stream gravels cover the floor of the shallow rock-rimmed trench to a depth of 8 to 16 feet, depending partly on the form of the bed-rock surface and partly on the irregularities of deposition by a swiftly flowing current. They form a flat, originally covered with timber and underbrush, ranging in width from 200 to 700 feet. The gravels of Chititu and White creeks and of the lower part of Red Creek consist of shale, limestone, sandstone, and quartz diorite porphyry, all of local origin, mingled with greenstone, diorite, and other rocks brought in by glacial ice from a foreign source. Shale, sandstone, and porphyry make up the fragmental deposits of the upper part of Rex Creek.

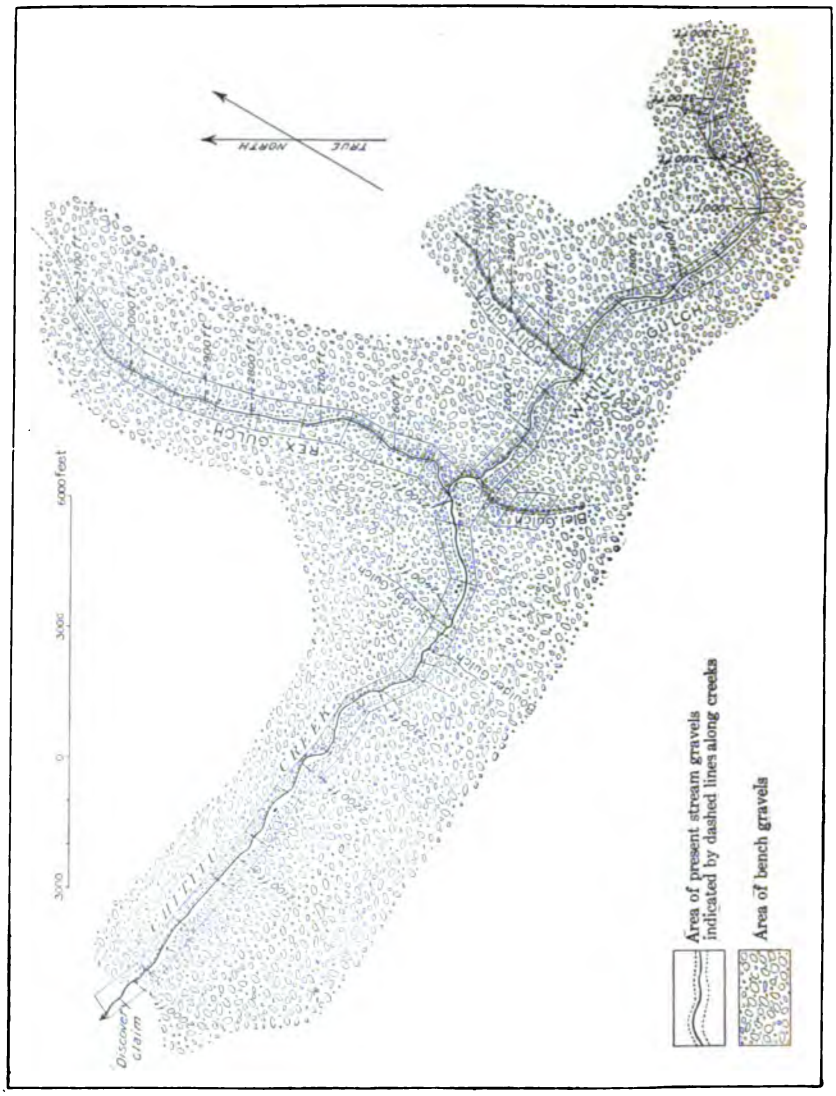

FIGURE 10.—Sketch map of a part of Chititu, Rex, and White creeks, showing the location of claims and the relation of bench and stream gravels.

Bowlders and large blocks make up a considerable portion of the gravel deposits, but not so large a proportion as on Dan Creek. Some of the glacial erratics are 6 or 8 feet in diameter. Most of the bowlders, however, can be sent through the sluice boxes, although it is necessary to break part of them with powder.

The gravels producing gold at present include those of Chititu Creek and of the lower part of Rex Creek. Very little work aside from that necessary to hold the claims has been done on White Creek for several years. In a general way the gold of Chititu Creek is distributed through the gravel from rim to rim of the rock channel, but it was found that at one place near the canyon there is a very well-defined pay streak, such as had not been found before on any of the claims farther up the creek. Most of the gold is on or near bed rock. Very little of it is found in the upper part of the gravel. The gold penetrates the bed rock through cracks and all openings. so that it is necessary to clean the rock carefully by hand after taking up the loose upper part to the depth of a foot or more. There are considerable differences in the character of the bed-rock surface, owing to irregularities in form and differences of hardness. In places the old stream has worn the rock smooth or has hollowed out cavities and depressions. Differences in the depth of weathering also add to the irregularities of the exposed surface, for the streams of water from the hydraulic giants cut away the loose rock and leave the harder parts standing in relief. Without doubt much of the gold of Chititu, Rex, and White creeks is a concentrated product from the bench gravels and the remainder is derived directly by weathering from the surrounding shales. All the bench gravels carry gold in some amount, and with decreased cost of mining it is probable that some of them will be exploited.

Chititu gold is finer and less worn than that of Dan Creek. It was found on the lower part of Chititu Creek that in a set of 4 screens ranging from 10 to 20 mesh about equal amounts of gold, by weight, were caught in each screen; at the mouth of Rex Creek it was estimated that from 25 to 40 per cent of the gold passes through a 16-mesh sieve. These results are in marked contrast with the heavy coarse gold of Dan Creek, yet both come from the same area of mineralization. There is, nevertheless, a little coarse gold on Chititu Creek, and several large nuggets have been found. The gold assays about $18.70 per ounce when cleaned. A large quantity of copper is obtained in the clean-up, and nuggets of native silver are common. Several other heavy minerals besides copper and silver are caught in the sluice boxes, such as pyrite, galena, stibnite, barite, and lead. Most of the lead was evidently introduced through the use of firearms, but some of the pieces examined did not resemble the battered bullets found in the sluice boxes and had a thick white coating of oxidized material. One of the largest of the native-silver nuggets was found in 1909; it weighed over 7 pounds but contained considerable quartz.

Native copper is a source of considerable difficulty and expense in mining. Several hundred pounds of fine copper are secured at every clean up and many large masses are taken from the cuts. Occasionally a large piece goes through the boxes and into the dump, but the largest are too heavy to be driven out of the cut by the giant. All the gold is picked over by hand to remove the fine copper not separated in the sluice box. During the early days of mining no effort was made to save the copper, since the expense of carrying it to the coast was greater than its value, yet with railroad transportation it should now be worth considering.

For the first few years after the discovery of gold on Chititu Creek mining was conducted on Rex and White creeks as well as on Chititu Creek. Rich ground was found on all these streams, and the principal operations were on the upper half of Chititu Creek, the lower end of Rex Creek, and the upper part of White Creek. All the work was done by hand and attention was directed to the richest ground only. At present two hydraulic plants are in operation, one on Chititu Creek and the other at the mouth of Rex Creek. Most of the claims on Chititu Creek are owned by the Nizina Mines Company and a complete hydraulic plant has been installed to exploit

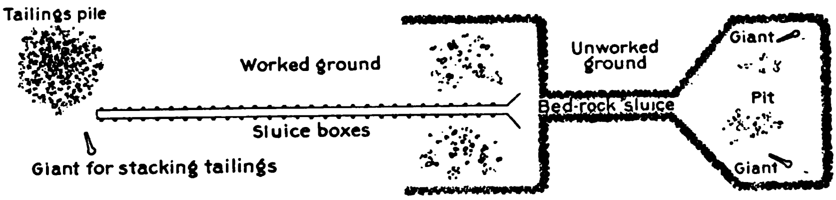

FIGURE 11.—Diagram showing the method of operating hydraulic giants on Chititu Creek.

them. This plant includes flumes, pipe lines, and giants, as well as a complete sawmill and an electric lighting system. The sawmill is equipped with planers and machinery for turning out standardized parts of flume and sluice boxes and riffle blocks and for putting them together. There is also a blacksmith shop and equipment for handling iron pipe. A very unusual feature for an Alaska placer mine is the complete system of accounting by which all expenses are charged in their proper place and the cost of any part of the operations is made known.

The method of handling gravel in the pit is shown in figure 11. When the sluice boxes have been put in place a bed-rock flume is carried upstream in the gravels as far as desired. Then the upper end of this cut is widened to 100 or 150 feet and a giant is placed on either side so as to drive the gravel along the sloping face into the head of the flume. By this method the force of the giants is added to the ground sluice water and a decided gain in efficiency is obtained over the former method of working against the face with the giants turned upstream and away from the sluice boxes. In practice only one giant is used at a time, the opportunity thus being given for a gang of men to remove the large bowlders on the opposite side. A giant is also required at the lower end of the sluice boxes to stack the tailings and keep the end of the boxes clear.

Mining operations at the mouth of Rex Creek have been conducted by Frank Kernan with a smaller plant than that on Chititu Creek, but they have been carried on for a longer time. A small giant is used and water is brought from Rex Creek in a flume. The conditions here are about the same as on Chititu Creek, but the width of gravel between the rock rims is less. Some very rich ground has been found on the lower end of Rex Creek and just below that on Chititu Creek.

The canyon of Chititu Creek is 4½ miles from the flats of Nizina River, and the character of the country is such that a good wagon road could be constructed at moderate expense. Such a road in connection with a bridge over the Nizina River would make communication with the railroad at Kennicott River easy and would be of great advantage to the miners of Chititu Creek, since it would enable them to secure supplies at any time of the year at a reasonable cost. It would also do much to solve the problem of securing labor at the time when it is most needed and thus prevent the necessity of carrying a large force of men on the pay roll during the whole season. Labor is a large item in the expense of operation at present chiefly because of the large amount of time spent in winter freighting. Wages range from $90 per month and board to $5 per day, with an additional amount to foremen.

Chititu Creek has a sufficient volume of water for all the demands that are made on it by the hydraulic plant in operation. The supply on Rex and White creeks is naturally less and probably would be inadequate for a large plant at some seasons of the year. Chititu Creek has a fall of 180 feet per mile from the forks to the canyon. Rex and White creeks have a fall of 250 feet per mile in the lower 2 miles of their courses. Thus a good head of water can be secured on each of these streams. There is an abundance of good timber for lumber and mining purposes on Chititu Creek below the canyon.

YOUNG CREEK.

Young Creek resembles Dan and Chititu creeks in having cut its channel through an old gravel filling in a glaciated valley. The present stream flows in a trench cut in black shales and lies from 20 to 40 feet below the base of the bench gravels. Its channel is in reality a shallow canyon whose walls are shale at the base and gravel above. Young Creek valley was once occupied by a glacier which came into it across a broad low divide near its head and was an overflow branch of the great Nizina Glacier. The gravels of Young Creek therefore contain a large amount of foreign material from the upper Chitina Valley in addition to rocks of the Kennicott formation and the greenstone from its own valley.

A large part of the creek has been staked for placer gold, although the production has not yet been enough to give much encouragement for mining. Two men were prospecting on the lower part of the stream in 1909. In previous years work was done on Calamity Gulch also, but the results were not sufficiently favorable to lead to its continuation.

Young Creek carries a large stream of water at all seasons of the year and has an average fall of 100 feet per mile above the Nizina flats. It is difficult to reach the upper part of the creek because of the canyon-like character of the stream channel and of the absence of trails above the creek on the hill slopes, and for this reason it is customary to cross the ridge from the head of White Creek and come down on Young Creek at the head of Calamity Gulch. This is the route always followed by prospectors bound for the head of Young Creek.

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DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, DIRECTOR

BULLETIN 449

A GEOLOGIC RECONNAISSANCE

IN

SOUTHEASTERN SEWARD PENINSULA AND THE NORTON BAY-NULATO REGION

ALASKA

BY

PHILIP S. SMITH AND H. M. EAKIN

WASHINGTON
GOVERNMENT PRINTING OFFICE
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CONTENTS.

ILLUSTRATIONS.

PREFACE.

By Alfred H. Brooks.

For several years after the organization of the Alaskan surveys in 1898 most of the appropriation was devoted to exploration. These exploratory surveys, although they had no high degree of accuracy, served to block out the larger features of the topography and geology, and the resulting reports and maps proved of great value to the pioneer prospector and miner. With the advance of the mining industry came a constantly increasing demand for maps which were based on a higher degree of refinement both with reference to geologic observation and to mensuration. To meet this demand areal surveys were begun first on a scale of 4 miles to the inch and later, where the mining interests warranted it, on a scale of 1 mile to the inch. The rapid industrial advancement in many parts of Alaska led to the expansion of surveys of this character almost to the exclusion of the purely exploratory work.

The progress made in reconnaissance and detailed surveys has seemed to warrant again diverting a part of the funds to exploring some of the little known regions. One of the largest of the unsurveyed areas in the more accessible parts of Alaska is roughly blocked out by lower Yukon and lower Koyukuk Rivers on the east and Norton Bay and Seward Peninsula on the west. This field was selected for survey because it was thought that the metamorphic rocks of the Seward Peninsula might occur within it, which would give presumption of the presence of auriferous deposits. The results of the investigation of this area are presented in this report.

In addition to exploring the region east of Norton Bay the party also extended the topographic and geologic mapping into the southeastern part of the Seward Peninsula, thus extending the surveys of Peters and Mendenhall, made in 1900. In this part of the field the results were sufficiently definite to warrant their publication in a map on a scale of 4 miles to the inch. The remainder of the survey, based as it was on foot traverses, which afforded little opportunity for areal mapping, seemed hardly sufficiently accurate to warrant the publication of maps on a larger scale than 16 miles to the inch.

Messrs. Smith and Eakin deserve great credit for the large amount of information gleaned during their very hasty exploration. The results form a notable contribution to the geology and geography of a region that was previously almost unknown. Though the economic results so far as most of the region is concerned are largely negative, they are, nevertheless, of no inconsiderable value. The geologic maps will indicate large areas which do not seem worthy of attention on the part of the prospector.

Besides covering the Norton Bay and lower Yukon region in an exploratory way, the report and its maps furnish the details about the southeastern part of the Seward Peninsula necessary to complete the reconnaissance work in that province. The publication of this report marks the close of the reconnaissance work in the Seward Peninsula which was begun a decade ago.

A GEOLOGIC RECONNAISSANCE IN SOUTHEASTERN SEWARD PENINSULA AND THE NORTON BAY-NULATO REGION, ALASKA.

By PHILIP S. SMITH and H. M. EAKIN.

INTRODUCTION.

West of Koyukuk and Yukon rivers a large area has long remained geologically unexplored. In a portion of this region an exploration party from the United States Geological Survey worked during the season of 1909, and the results of the studies there carried on and extended as far as Council, in Seward Peninsula, are set forth in this report. The party consisted of the writers, A. G. Winegarden, packer, and a cook. Supplies for a month were shipped to Nulato, the point from which the expedition set out, and the camp equipment and supplies were transported in the field by a pack train of four horses. Other supplies, sufficient to last the rest of the season, were sent to Nome and then transported, through the courtesy of the Wild Goose Company, to the mouth of the Koyuk and there cached to await the arrival of the party.

After many delays the party arrived in Nulato on the afternoon of June 24 and immediately began to get the outfit into condition for the trail. On the morning of June 26 active field work was begun. The route, as indicated by the location of the camps on the maps (Pls. I and V, in pocket), was westward to Ungalik River, thence northward to the Koyuk, which was reached on July 16. Here a halt was made until supplies from the cache could be obtained and the outfit put into shape for the next trip. On July 19 the party started northeastward along the divide between the Inglutalik and the Koyukuk drainage basins. This survey was carried eastward to the divide between Kateel and Inglutalik rivers. Return to the Koyuk was made along the divide between the drainage basins of the Buckland and the East Fork of the Koyuk, and a tie was made on the previous geological work of Moffit in northeastern Seward Peninsula. At the close of the trip the Koyuk was crossed near the mouth of East Fork, and the party arrived at the Koyuk cache on August 8. A severe storm and the work of replenishing supplies and making necessary repairs delayed setting out again until August 12, when the party got under way and made a meandering traverse of the areas between Koyuk River and Norton Sound that had not been visited by Mendenhall in his expedition of 1900. Moving along the divide between the Koyuk and the Norton Sound drainage basins, the party swung around the head of the Tubutulik, thence crossed the divide into the Fish River drainage basin, and, following along the foothills, came to the Omilak mine. From the mine the course was southeastward to the Kwiniuk and thence along the coast to Walla Walla. Supplies had been sent to this point from the mouth of the Koyuk, so that the horses had been able to travel light. From Walla Walla meandering traverses were made westward to Cheenik, which was reached September 17. By this time the top of the ridges were snow covered, and a start was made the next day for Council by way of the Kachauik-Fish River divide. Council was reached and the fieldwork for the season was stopped on September 21.

Locations were kept by continuous foot traverses run by each of the geologists independently and elevations were frequently noted by aneroid barometers. The barometric observations, however, were unchecked and served principally to give relative elevations. The foot traverses were paced, directions being obtained by means of Brunton compasses. The results of the different traverses were platted in the office by making adjustments between known points which had been determined instrumentally either by the Coast and Geodetic Survey or by Peters on the reconnaissance trip of Mendenhall in 1900. So closely did the various traverses check on known points that it is believed that, after the adjustments were made and the map prepared, few, if any, points were more than a mile out of their correct positions. That this apparently rough method of pacing is capable of giving good results is shown by the fact that the difference between the position of Camp A15, near the Bonanza mine, on the Ungalik, as determined by the two geologists, after having made a linear traverse of over 130 miles, was less than 5 miles. This result was obtained on the erroneous premise that both were pacing 2,000 paces to the mile. When, however, an individual rating had been obtained by comparing the scaled and paced distance to the mouth of the Koyuk and this correction had been applied to the location of Camp A15, it was found that the difference between the two traverses was considerably less than 1 mile.

Hearty acknowledgments are due to Mr. A. G. Winegarden, of Gardiner, Mont., who acted as packer throughout the various trips, for his unceasing activity in furthering the aims of the expedition and his willingness to perform more than his share of the camp work in the face of rather discouraging conditions. Thanks are also expressed for the friendly assistance of Mr. C. H. Munro, of the Wild

Goose Company, and to Messrs. Thomas Moon and John Lindburg, prospectors, in distributing supplies at appointed places and thus facilitating the movements of the party.

The writers desire also to express their appreciation of the work of the earlier geologists and engineers who have visited portions of the region or contiguous areas, and from whose published reports and manuscripts they have borrowed to supplement their own observations. Among those to whom the writers are most indebted for scientific information are Messrs. J. L. McPherson, W. C. Mendenhall, F. C. Schrader, F. H. Moffit, and A. H. Brooks; for the determination of the fossils collected they are indebted to the paleontologists of the United States Geological Survey.

GEOGRAPHY.

LOCATION OF AREA.

The area in which new geographic and geologic information has been obtained may be inferred from the description of the itinerary of the expedition of 1909. It has seemed feasible, however, to so extend the area actually visited as to include contiguous regions which throw light upon parts of the region visited in 1909 or in which the results of 1909 serve to confirm or explain problems raised by other investigators. The area treated in this report is therefore in the main rectangular and may be roughly described as bounded by parellels 64° and 66° north latitude and by meridians 156° and 164° west longitude. Described in terms of places and natural objects, the southern margin is near the settlement of Unalaklik, on the east coast of Norton Sound, and the eastern end of the northern margin is a short distance north of the big bend of Koyukuk and Kateel rivers and the western end is a short distance north of the town of Candle on Kiwalik River in the northeastern corner of Seward Peninsula. On the east the region is bounded by a north and south line passing a little east of the junction of the Melozitna and Yukon rivers; on the west the best known point to which to refer the margin is the town of Council on Niukluk River. The area can be best comprehended by reference to the general map of northwestern Alaska (fig. 1), and to the more detailed maps, Plates I and V. For several reasons it has been decided to show the eastern part of this region separately from the western. This has been done mainly because better information has permitted mapping of the western portion on a scale of approximately 4 miles to the inch, whereas the eastern portion is shown on Plate V on a scale of approximately 16 miles to the inch. A division of this sort separates the great sandstone shale area of the east from the more highly metamorphic areas of the west. In this report the eastern area, the one represented by

Plate V, will be referred to as the Nulato-Norton Bay region, and the western part (Pls. I, VI) will be called southeastern Seward Peninsula.

HISTORY OF EXPLORATION.

Prospectors and trappers have without doubt wandered over the region described in this report, but there is little or no record of their journeys and the facts that they learned have been lost. Other classes of travelers seldom ventured far from the main avenues of intercommunication; consequently, until within the last 10 or 15 years there have been few published references to any part of the

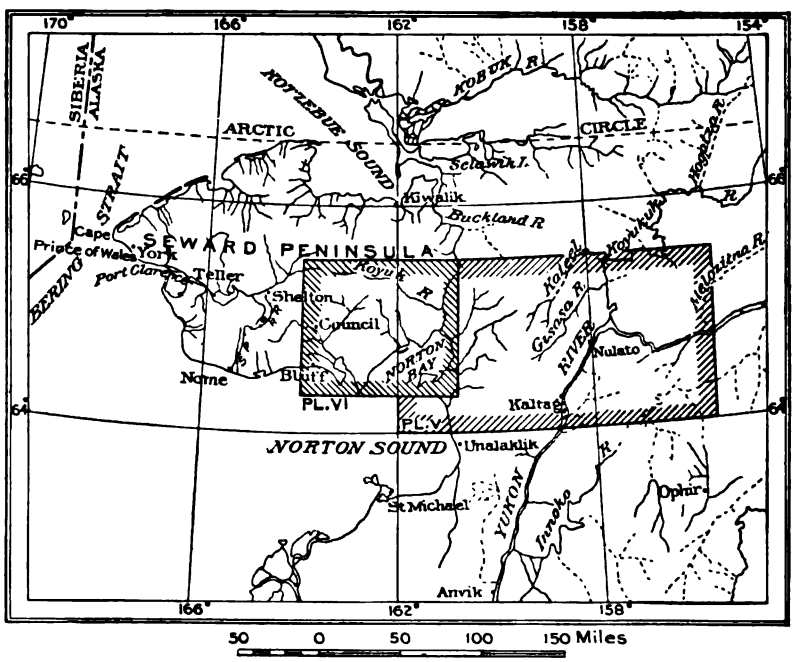

FIGURE 1.—Sketch map of northwestern Alaska, showing location of region considered.

region except the coast line, the Yukon and Koyukuk rivers, and the Kaltag portage. It is not intended at this place to give an account of all the exploring expeditions that have visited the waters surrounding Seward Peninsula, Norton Sound, and Bering Sea, and the reader who desires a more complete historical sketch is referred to the papers of Brooks[a] and Dall.[b]

The oldest settlement in this part of Alaska was at St. Michael, where, according to Dall,[c] Michael Tebenkoff, an officer in the Rus-

[a] Brooks, A. H., Geography and geology of Alaska: Prof. Paper U. S. Geol. Survey No. 45, 1906.

[b] Dall, W. H., Alaska and its resources, Boston, 1870, 627 pp. and map.

[c] Idem, p. 9.

sian-American Trading Company, established a post in 1833. From this point trading was carried on with the surrounding country. Soon other posts were established. Thus in 1838,[a] Malakoff, a creole, explored the Yukon as far north as the present town of Nulato and established a small settlement at the mouth of Nulato River. He left this post undefended during the winter of 1838–39 and it was destroyed by Indians. Soon afterward, in 1840, a trading post and fort were established on Norton Bay near the mouth of Unalaklik River and called by the name of the stream. This town, according to the 1900 census, had a population of 241.

In spite of the destruction of the first settlement at the mouth of Nulato River the Russian-American Trading Company, appreciating the importance of this place as a point giving ready access to the Koyukuk basin, sent Dérabin in 1841 to rebuild the fort. This was done, and in 1842 Lieutenant Zagoskin of the Russian navy visited the place. His visit is of interest because he made several short journeys into adjacent areas and published the results of his observations.[b] Although his accounts are fragmentary and imperfect, they show that he visited portions of Yukon River as far upstream as the mouth of the Melozitna, explored Koyukuk River as far as the mouth of the Kateel, and made a side trip up the Kateel to assure himself that the native reports of an easy route into the Buckland drainage basin were correct. Unfortunately the maps published with his report are not based so much upon his direct personal observations as upon reports heard by him, and consequently many of the features are indicated only in a most general manner.

In 1851 the trading post and fort at Nulato were burned and some of the inhabitants were massacred by Indians from the Koyukuk. When the town was rebuilt it was moved a mile or more up the river to its present location on a low gravel bench between Nulato Slough and Nulato River.

About 1850 the great activity among many of the different nations, notably the English, in searching for the Franklin expedition resulted in several ships wintering in the waters of Kotzebue Sound. From these ships several exploring parties visited neighboring areas and added geographical data. Of these expeditions few prepared maps of sufficiently large scale to portray any but the most general features of the region explored. Among the overland trips were the exploration of Selawik Lake and vicinity by Surgeon Simpson of H. M. S. *Plover*, the trip from Chamisso Island by way of Buckland and Koyuk rivers to St. Michael by Lieutenant Pim of the same

[a] Dall, W. H., Alaska and its resources, 1870, p. 48.

[b] Zagoskin, L. A., Travels on foot and description of the Russian possessions in America from 1842 to 1844: Ermans Archiv für wissenschaftl. Kunde von Russland, vols. 6 and 7.

ship, and the exploration of Buckland River by Captain Kellett and officers of H. M. S. *Herald*. Accounts of the voyages of the *Herald*[a] show that the last-named expedition went up the Buckland for 30 miles (probably measured along the circuitous course of the river) in a whaleboat and then about 30 miles farther in lighter boats. The Pim journey is also described in the same publication, but the narrative is more a recital of hardships than of geographic or geologic data and is not accompanied by a map.[b]

A later impetus to exploration was given when in 1863 the Western Union Telegraph Company undertook to build a telegraph line through Alaska to connect the settled parts of America and Europe. In 1865 Kennicott, who was in charge of the scientific work of this company, crossed the Kaltag portage and surveyed the route to Nulato. During the same year J. T. Dyer and R. D. Potter, according to Dall,[c] made a very hazardous and successful exploration of the country between Norton Bay and the mouth of the Koyukuk River on the Yukon. Unfortunately no map of this trip was published, and the data collected, although undoubtedly used by Dall,[d] have never been available. In 1865, also, another party under the leadership of Baron von Bendeleben explored the route for the line from Norton Bay to Port Clarence, but the results like those of the other parties have never been published.

The death of Kennicott in 1866 caused the leadership of the scientific corps to pass to W. H. Dall. It was the work accomplished while in charge of the telegraph exploration and during the year succeeding the abandonment of the enterprise that enabled Mr. Dall to write the most authoritative general book on Alaska that had appeared up to the time of the discovery of valuable gold deposits. All branches of geography and geology received some attention from this investigator and many of his observations will be quoted in more detail in subsequent portions of this report.

A period of ten or fifteen years elapsed during which few notes of value were collected and published concerning the Nulato-Council region. In 1885 Lieutenant Allen made his famous trip, during which a portion of the Koyukuk was mapped and also the portage from Kaltag to Unalaklik. About this time explorations by the Revenue-Cutter Service were begun. The explorations of this branch of the government service which directly concerned the Nulato-Council region were by Purcell in the vicinity of Selawik Lake and by Zane along the Koyukuk to Nulato.

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[a] Seeman, Berthold, Navigation of H. M. S. *Herald* during the years 1845–1851, vol. 2, London, 1853, pp. 119–120.

[b] Op. cit., pp. 130–148.

[c] Dall, W. H., Alaska and its resources, p. 357.

[d] Op. cit., map.

In 1889 Prof. I. C. Russell[a] ascended the Yukon, and his report of this trip furnished many facts, both of geologic and geographic significance.

With the discovery of gold in the Klondike an influx of prospectors and others into Alaska followed, and soon afterwards the United States Geological Survey was able actively to undertake geographic and geologic investigations of the district. One of the earliest of these surveys was conducted by Spurr,[b] mainly in the basin of the Kuskokwim. The geologic and topographic map published with his report covers the area between the Koyukuk and the Koyuk and from the mouth of the Kateel southward, and is consequently the first geologic map of the eastern half of the area studied in 1909. Most of the information concerning the Nulato-Council region was compiled or gathered from reports of prospectors, and very little geographic significance, outside of the distribution of the different geologic groups, was added.

Schrader[c] in 1899 came down the Koyukuk and the maps published in the report of his trip, which were made by T. G. Gerdine, afford a much more detailed representation of the region than had hitherto been available. No traverses of the country away from the river were made, so that details regarding the region between the Yukon and Norton Bay were not acquired. At the close of the field work in the Koyukuk region Schrader went to Nome and with Brooks made the first examination by Survey geologists of Seward Peninsula.

In 1900 two main parties were dispatched to Seward Peninsula. One in charge of A. H. Brooks investigated the region as far east as Council; the other in charge of W. J. Peters, with W. C. Mendenhall as geologist, investigated the southern part of the peninsula as far east as the Koyuk. The field studies of the Peters party cover the western part of the area visited by the expedition of 1909 and will be referred to in detail in succeeding pages of this report. In the main, however, the results may be summarized as follows: A delineation of the major features of the topography by maps, the publication of data on various geographic subjects such as climate, vegetation, and fauna, and the statement both verbal and graphic of the areal, historical, and economic geology.[d] The studies of Mendenhall were carried on mainly from the streams; the three larger ones, the Fish, the Tubutulik, and the Koyuk, he ascended in canoes.

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[a] Russell, I. C., Notes on the surface geology of Alaska: Bull. Geol. Soc. America, vol. I, pp. 99–162.

[b] Spurr, J. E., A reconnaissance in southwestern Alaska in 1898: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 7, 1900, pp. 31–264.

[c] Schrader, F. C., Preliminary report on a reconnaissance along Chandlar and Koyukuk rivers. Alaska, in 1899: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, pp. 441–486.

[d] Mendenhall, W. C., A reconnaissance in the Norton Bay Region, Alaska, in 1900, a special publication of the U. S. Geol. Survey, 1901, pp. 183–222.

During 1901 Schrader made a trip to northern Alaska and visited portions of the Koyukuk drainage basin.[a] In the same year Mendenhall[b] explored the Kobuk River, and although this region lies considerably to the north of the Nulato-Council area the information secured throws considerable light on the problems of the latter. In the reconnaissance by Schrader, a geologic map was published showing the different formations along the Koyukuk northwestward from latitude 66° north, and this map and the notes on the lower part of the river already referred to on page 15 afford a continuous section from the Yukon northward.

Of the other survey expeditions that have visited contiguous areas the party under Collier in 1902 and the Atwood party of 1907 are the only ones that require specific reference here. The main object of these expeditions was to study the coal resources of portions of Alaska. A publication has appeared setting forth the results of the investigations by Collier,[c] but Atwood's report has not yet been published, though many of the manuscript notes have been kindly furnished to the present writers.[d]

In 1906 a traverse from the mouth of the Koyukuk to the shores of Norton Sound and thence to Council was made by a party sent out by the War Department. The object of the survey was to determine the feasibility of a land route from the navigable waters of the Tanana to the vicinity of Council City. The maps accompanying the report of this survey were the first to give accurate information concerning a strip of country 5 to 10 miles wide extending from the mouth of Koyukuk to the mouth of the Koyuk, and are replete with facts of geographic interest. J. L. McPherson was in charge of the field work and prepared the text of the report.[e] Specimens of the various formations crossed were collected and submitted to the United States Geological Survey for study. On this account it was not necessary to cover the area surveyed by McPherson's party again when the Nulato-Council region was visited in 1909. Reference to this report will be made in more detail in subsequent pages of this paper.

In 1908 A. G. Maddren made an exploratory survey of Innoko River and contiguous areas. His report on this trip, with the accompanying maps, affords considerable information concerning the

[a] Schrader, F. C., Reconnaissance in northern Alaska in 1901: Prof. Paper U. S. Geol. Survey No. 20, 1904, 139 pp.

[b] Mendenhall, W. C., Reconnaissance from Fort Hamlin to Kotzebue Sound, Alaska: Prof. Paper U. S. Geol. Survey No. 10, 1901, 68 pp.

[c] Collier, A. J., Coal resources of the Yukon, Alaska: Bull. U. S. Geol. Survey No. 218, 1903, 71 pp.

[d] Atwood, W. W., Geology and mineral resources of parts of the Alaska Peninsula: Bull. U. S. Geol. Survey No. 467, in preparation.

[e] McPherson, J. L., Reconnaissance and survey for a land route from Fairbanks to Council City, Alaska: Sen. Doc. No. 214, 59th Cong., 2d sess., 1907, 22 pp., 7 maps, 6 plates.

country south of the Yukon. Practically all the features shown on Plate V south of the Yukon were taken directly from his maps.[a]

GENERAL TOPOGRAPHY.

Throughout the Nulato-Council region the relief is relatively low. Few hills over 3,000 feet occur and the larger part of the upland area is only about 2,000 feet above sea level. Although there are no high ranges, steep slopes lead from the flat river bottoms to the highlands. In the Nulato-Norton Bay region there are numerous parallel northeast-southwest ridges, the highest of which forms the divide between the Inglutalik-Ungalik and the Kateel-Gisasa river basins. The hills to the north of the East Fork of Koyuk River are low and rolling, without pronounced direction. Farther west, in Seward Peninsula, there are three ranges forming prominent landmarks; these are the hills between Buckland and Kiwalik Rivers, and the Darby and the Bendeleben Mountains. The higher points of the first range rise to elevations of about 2,500 feet; in the Bendeleben Mountains the highest point is a little over 3,700 feet, and in the Darby Range the highest peak is about 3,000 feet. In the two last-named ranges precipitous slopes more than 2,000 feet high give a very rugged topography.

Outside of these three higher areas the uplands are rolling, with elevations from 1,000 to 2,000 feet above sea level, unforested, well drained, and covered with angular fragments of frost-riven waste. Pinnacles of the underlying rocks form fantastic knobs here and there.

The drainage of the region studied flows into the Yukon, into Norton Bay, into Norton Sound, or into Kotzebue Sound. The streams belonging to the Yukon drainage and to the eastern part of Norton Bay show pronounced parallelism with the geological structure, and long, narrow valleys are the result. The gradients of the main valleys are low, but those of the small side streams rise rapidly headward. In places the streams flow through narrow rock-walled canyons of slight depth, but in others flat flood plains and gravel deposits occur. In the headward portions of the basins complex relations of the streams on opposite sides of the divide are noted, and it is by no means possible at long range to foretell the direction of the drainage. In Seward Peninsula, where the geologic structure is more complex, the effect on the streams is not well marked and irregular courses are the rule. In this part of the area the longer streams, such as the Koyuk, the Kiwalik, and the Tubutulik, flow more or less parallel

[a] Maddren, A. G., The Innoko gold-placer district, Alaska: Bull. U. S. Geol. Survey No. 410, 1910, pls. I and II.

with the mountains, but Fish River and its larger tributaries flow at right angles to the Bendeleben Range.

Almost all the valleys show signs of having been eroded entirely by stream action. In the headwaters of the rivers rising in the Bendeleben and the Darby Ranges, however, there are glacial cirques and valleys. Here the present streams form irregular threads on the broadly open floors of valleys with very steep sides. At the mouths of the streams flowing into Norton Bay many of the streams, instead of showing erosion features, have filled the former valleys, which have been depressed, with sand and gravel. Examples of this kind of topography are found at the mouth of the Kwik, the Tubutulik, and the Kwiniuk Rivers, where numerous lakes and sloughs form an untraversable network during the summer.

The coast line presents numerous examples of different types of shore topography. From the Reindeer Hills to the Koyuk a coastal plain, recently emerged, affords a relatively straight shore with such slight depths of water off the coast that approach for large vessels is impossible. Of course, under such conditions, harbors do not exist. On the western side of Norton Bay the sinking of the land and the attack of the waves have resulted in a rugged coast with cliffs and harbors. This part of the coast is formed by the Darby Range, which rises in abrupt slopes from the sea and forms a long southward pointing peninsula. West of this range the deep reentrant of Golofnin Sound and Bay, which probably represents the submerged portion of an old valley similar to that of Fish River, affords a good harbor. Still farther west rocky headlands with intervening beaches produce a diversity of forms. On the depressed portions of the coast there are sand spits, such as the long point extending east from near the mouth of the Kwiniuk.

DRAINAGE BASINS INCLUDED.

All the streams flowing through the Nulato-Council region may be considered as belonging to one of three main basins, namely, the Yukon, the Norton Sound, and the Kotzebue Sound. Of these the first two include by far the greater number of streams. Roughly computed about 50 per cent of the area shown on the maps, Plates I and V, is drained by the Yukon and its tributaries, 45 per cent by tributaries to Norton Sound, and 5 per cent by streams flowing into Kotzebue Sound. In the description of these different basins no attempt will be made to enumerate all the streams belonging to each, for that sort of information may be better gathered from the maps (Pls. I and V), but rather to present the particular features not easily legible on topographic maps of such scales as those adopted for publication.

YUKON BASIN.

The portion of the Yukon considered in this report extends from slightly east of the mouth of the Melozitna on the northeast to near the mouth of Kaiyuh Slough on the southwest. In this distance the main tributaries are the Koyukuk, the Nulato, the Kaltag, and the Khotol. Regarding these various streams, with the exception of the first two, no new data of geographic interest were received during 1909, and as the facts already known about the Kaltag and the Khotol are indicated on the map accompanying these reports, no further description of them will be attempted.

Kateel and Gisasa rivers formed the portions of the Koyukuk drainage that were visited and mapped, but only the upper 30 to 50 miles of each stream were seen in any detail. McPherson, who crossed the Gisasa near latitude 65° North, describes the valley as follows:[a]

> The Gisasa River is a stream from 70 to 150 feet wide, with gravelly bottom. Along the river banks on the north side of the valley is a heavy growth of spruce. Along the south side of the valley timber grows in scattered bunches, the intervening ground being to a considerable extent marshy and niggerhead tundra.

From the survey of 1909 it was found that the Gisasa Basin was a peculiar, narrow one, lying between the Nulato on the southeast and the Kateel on the northwest. The river from mouth to head near Camp A9 must be nearly 70 miles in a direct line. In this distance few or no tributaries much more than 10 miles in length are received. The basin is thus probably less than a score of miles wide in its widest part, and in the headward 50 miles it is generally much less.

As will be shown in a later portion of this report the direction and the general physical features of the Gisasa Valley are due to the geologic structure of the region, which trends northeast-southwest. Although in portions of its course the river flows on a flat gravel plain essentially at the level of the stream, in other parts it has rock walls through which the stream has cut narrow canyons. These canyons are not continuous, but appear at irregular intervals along the valley. None of the canyons are deep, only a few of the rock walls, if any of them, reaching a height of 50 feet. Above the steeply incised walls a more open valley is usually found, which indicates rather recent minor deformation of an anterior topography.

The Kateel Basin was seen in less detail by the writers, but its general features are essentially similar to those of the Gisasa, except that its valley is wider and it has longer tributaries. From the survey of McPherson it was determined that Arvesta and Caribou creeks are tributaries of the Kateel. The former, where it was crossed, near latitude 65° north, is from 50 to 70 feet wide and from 1 to 3 feet deep. The latter is much smaller and runs at an elevation

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[a] McPherson, J. L., op. cit., p. 17.

about 500 feet higher. Prospectors who crossed the region somewhat north of McPherson's route state that the volume of the Kateel is much smaller than that of the Gisasa.

A general idea of the Kateel Basin was afforded by a view from Traverse Peak, though the weather was unfavorable for a thoroughly satisfactory observation of the topography. From this point it was evident that the northeasterly trend observed in the Gisasa Valley was still dominant. The divide along the western margin of the basin ran nearly north and south, so there is a considerable area tributary to this river. Low passes lead from the Kateel into the Ungalik, or into the Inglutalik, and probably into the Buckland. The pass from the Kateel to the Buckland was not actually seen, but enough of the drainage arrangement was evident to show that some of the western tributaries joining the Kateel below its junction with Arvesta Creek head in the low hills east of the Buckland, so that an easy route undoubtedly exists between the two rivers.

The Nulato River Basin is long and narrow, being formed by two large streams occupying strike valleys that coalesce a few miles from the Yukon and below this point are transverse to the structure. The main branch is about 50 miles long in a straight line. Its valley has a broad gravel-filled floor on which the stream meanders in irregular pattern. It will be seen from the map of this valley that, although lying parallel with the Yukon and not more than 20 or at most 25 miles away from that stream, it drains northeastward, whereas the Yukon in that part of its course flows southwestward. This results in a more than right-angled turn near the mouth of the Nulato, and suggests that the physiographic development of the streams has been complex. Smooth slopes rise steeply from the valley floor to the relatively even uplands. On the southeastern side high hills scored by narrow gulches preserve the snowfall late in the summer. The volume of water carried by the main branch is therefore more constant throughout the season than is the case of those streams dependent upon the rainfall. Passes easily traversable by horses lead from the Nulato Basin to that of the Gisasa, of the Shaktolik, and probably also of the Unalaklik.

NORTON SOUND DRAINAGE.

TRIBUTARIES OF NORTON SOUND EAST OF KOYUK RIVER.

East of Koyuk River the main streams belonging to the Norton Sound drainage from south to north are the Unalaklik, the Shaktolik, the Ungalik, and the Inglutalik. All of these rivers show pronounced angular bends on a large scale, most of which are to be accounted for by the geologic structure of the region. This condition is best illustrated by the three northern streams, whose basins are almost completely mapped. It will be seen from the map that for the first 5 or 10 miles[a] in a straight line from the coast the rivers flow in winding courses at a right angle to the shore. Upstream from this point the course abruptly changes, and for the next 10 to 30 miles the rivers have a nearly north-south trend. Still farther upstream the direction again changes, and the streams flow from the northeast or even from the east-northeast.

Taken as a whole, the three rivers have narrow, rather contracted basins in the middle or north-south part of their courses, because few tributaries enter from the east and west; in the upper part, however, because the main streams are flowing more or less across the geologic structure, the side streams are long and the area tributary to the main streams is therefore more extensive. Rock-walled canyons, separated from each other by gravel-filled basins, bear witness to recent crustal movements throughout the area.

Unalaklik River was not visited by the survey party in 1909, but portions of it are well known, because the portage from the Yukon to St. Michael follows the lower part of this stream. A long branch joining from the north heads against the Shaktolik River, and it is probable that an easy pass across the hills to Nulato River exists. The northeast-southwest trend of the drainage and the intricacy of stream arrangements make it difficult to interpret the topography at long range. It is possible, therefore, that the Shaktolik may extend farther around the head of Nulato River than was evident at a distance, so that there may be more than one divide between Nulato and Unalaklik rivers.

North of the Unalaklik is a rather small stream, the Iguik, which drains the triangular area between the Unalaklik and the Shaktolik. Its drainage basin is at most only a few hundred square miles in area.

Although previously mapped as a rather unimportant river, the Shaktolik drains a considerable territory between the Ungalik on the north and the Unalaklik on the south. Its course is so irregular that it can with difficulty be recognized at any considerable distance. The Shaktolik was first seen in detail near camp A10. At this place its course was nearly due north, giving the impression that it flowed northward into the Ungalik. Near camp A13, however, it joined with a branch from the south and formed a good-sized stream. From the small increase in the size of the northern branch between camp A10 and its junction east of camp A13 it seems certain that only a few tributaries enter between these two places.

Near camp A10 the river is incised in a narrow rock-walled canyon about 30 feet deep. Above the canyon walls the topography opens out into a broad older valley which had reached maturity before the uplift took place by which the present cycle was started. The floor

[a] The figures given represent measurements in an air-line and not along the circuitous courses of the streams.

of this older valley is in large measure rock cut with a relatively small amount of gravel covering. Well-rounded material, however, is practically universally present and affords indisputable proof of the presence of stream erosin at this higher level. Near camp A13 the canyon-like character is wanting. Four or 5 miles below camp A14 incised meanders, with radii of from one-half mile to 1 mile, occur. Here the walls are, for the most part, gravel, with the bed-rock not exposed. It is believed that the differences in the amount of filling and incision noted along this stream are due to the undulatory character of the most recent uplift.

No accurate determinations were made of the volume of the Shaktolik, but from float measurements near camp A12 it was found that the discharge was between 150 and 200 second-feet. The tributary from the north joining east of camp A13 was of about equal volume, and below camp A14 the amount of water had increased to such an extent that the stream could be crossed only with difficulty. In this connection it should be noted that 1909 was an exceptionally dry season, so that a greater volume is to be expected during a year of normal precipitation.

Ungalik River shows the same characters as the other streams tributary to Norton Bay from the east. Its basin shows the three distinct parts previously referred to, namely, an open east and west course through the coastal plain province, a narrow north and south portion parallel to the geological structure of the region, and a northeast and east-northeast course in the headward portion. In this upper part the basin shows the same feature previously noted on the Shaktolik, namely, that the tributaries from the south are longer than those from the north, so that the basin, if the main stream be considered as its axis, is decidedly unsymmetrical. This lack of symmetry seems to be due to three causes, namely, structural control, climatic conditions, and tilting. Asymmetrical valleys are common in Alaska, and have previously been described by different authors. An epitome of the various causes with reference to a specific region has been published by Goodrich.[a] It was pointed out by this geologist that the effect of insolation differs according to the condition of the stream as to load; thus, if the stream is overloaded, the tendency will be for the waste to push the stream toward the side receiving the least sun, whereas, if the stream is not carrying all the material it can the reverse tendency will dominate, and the stream will migrate toward the side receiving the most sun. Plate II, *A*, shows one of the tributaries of the Shaktolik below camp A12, which is migrating toward the north because the stream is underloaded and the south-facing slope receives more warmth than the

[a] Goodrich, H. B., Cause of asymmetry of streams: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1898, pp. 285–289.

A. ASYMMETRIC VALLEY, SHAKTOLIK BASIN.

B. UPLANDS BETWEEN EAST FORK AND INGLUTALIK RIVER.

other. In a consideration of the development of the drainage it should be borne in mind that types due to one cause alone are practically absent and that complexity of origin, rather than simplicity, is normal.

From Ungalik River passes may be found into the Inglutalik to the north or to the Kateel on the east, or into the Shaktolik on the south. None of these passes are over 3,000 feet above the sea, and many could be found at elevations below 2,500 feet. The saddle by which McPherson crossed from the Kateel to the Ungalik was only a little over 2,000 feet.

As regards size, the Ungalik is not so large as the Shaktolik. Two miles below camp A16 the stream could be crossed in less than 2 feet of water, and farther upstream it was still shallower except for occasional deep holes. Lower downstream, however, in the coastal plain portion of its course, it becomes deeper and sluggish, and instead of a hard gravelly bottom it has a soft mud bottom that makes crossing difficult without a boat.

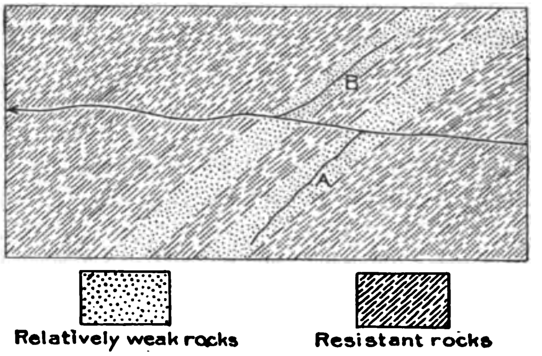


FIGURE 2.—Arrangement of drainage due to geologic structure.

Inglutalik River derives its name from the Eskimo words meaning "river of bones," in reference to the number of mastodon and other bones found in the terrace of gravels along its course. It is at least 60 miles long and appears to have a greater volume of water than either the Shaktolik or the Ungalik. Below camp A18, in the coastal plain province, the river can not be forded; at camp A18 is the first riffle, and on it good crossing in about 2 feet of water is afforded. Poling boats have been taken as far as camp B9, and during seasons of normal precipitation could undoubtedly be worked still further upstream.

In the upper part of the Inglutalik Basin the drainage is very complex, and many readjustments have taken place, so that at a distance of 5 or 6 miles it is impossible to tell whether the river drains toward the north or the south. Backhand or barbed drainage is common. It should be noted, however, that this feature is not always to be accounted for by capturing, but in many instances is due to the geological structure. Figure 2 indicates in diagrammatic manner how a normally developed subsequent stream (A) may have a barbed junction with the main stream without capturing having taken place. In this same figure stream B is also a normally developed subsequent stream, but as the soft bed on which it has developed forms an acute angle with the course of the main stream the tributary enters without the barbed junction.

Low passes easily traversed by horses lead from the Inglutalik into the Kateel basin to the northeast; into the Ungalik on the south; into the Koyuk on the west; and into the Buckland on the north. It is reported, although it was not confirmed by personal observation, that part of the Selawik drainage also heads against the Inglutalik. There are no known facts which would make such a condition unlikely, but the region in question is so entirely unexplored that conjectures as to the drainage are hardly warranted. The only information on this subject is Zagoskin's trip up the Kateel to near the big bend, in 65° 30′ north latitude. According to this traveler a low pass leads from near this point northwest to the Buckland. It should be realized, however, that Zagoskin did not attempt the passage; that there may have been a misunderstanding as to the river on the western side of the divide, and that it is possible his informants were not correct in their geography. From the present status of knowledge it seems more likely that a pass northwest of the big bend of the Kateel would lead into a north-flowing branch of the Selawik than to a west-flowing branch of the Buckland.

KOYUK RIVER.

Koyuk River enters the northern reentrant of Norton Bay and is a river over 80 miles long. For the first 15 miles from the mouth it has a nearly southerly course, but above this point it flows more or less directly from the west toward the east. For 60 miles or so its tortuous meanders make measurements along the river many times the air-line distance. Mendenhall and Peters in 1900 traversed the river as far west as the head of canoe navigation a few miles above Knowles Creek, and the details of their map have been taken for the course of this stream. In 1903 [a] Moffit and Witherspoon, mapping the northeastern part of Seward Peninsula, added many facts concerning the Koyuk basin north of the main stream and concerning the river itself beyond the point reached by Mendenhall and Peters in 1900.

From the observations of the earlier geologists and topographers, supplemented by the field work of 1909, it appears that the Koyuk basin is unsymmetrical. Of the various tributaries, East Fork undoubtedly drains the largest territory. Its basin is about 30 miles long, heading against portions of Buckland and Inglutalik river basins. Many low passes lead from the East Fork basin into the

[a] Moffit, F. H., The Fairhaven gold placers, Seward Peninsula: Bull. U. S. Geol. Survey No. 247, 1905, pls. II and III.

Buckland. Probably the lowest pass is by way of the branch on which camp B12 was located. The elevation of this camp was approximately 300 feet above the junction of East Fork and the Koyuk, and as there is a strong upstream current, due to the tides, as far as the mouth of Peace River, it is safe to assume that the mouth of East Fork is practically at sea level. North of camp B12 there is a broad abandoned valley in which there are several lakes. Some of these drain northward and some southward. The elevation of these lakes is not more than 100 feet above the camp, so it is certain that there is a route across Seward Peninsula from Norton Sound to Kotzebue Sound, nowhere more than 400 feet above sea level.

TRIBUTARIES OF NORTON SOUND WEST OF KOYUK RIVER.

West of Koyuk River the main tributaries of Norton Sound from east to west are Kwik, Tubutulik, Kwiniuk, and Fish rivers. All of these streams are mainly within the area occupied by metamorphic rocks of complex structure and consequently do not show by their courses the striking structural control noted in the rivers farther east. Because of the greater amount of information available concerning the region west of the Koyuk, the map of southeastern Seward Peninsula (Pl. I) shows the distribution and character of these rivers in greater detail than was possible on the smaller scale map adopted for the Nulato-Norton Bay region (Pl. V).

Kwik River is a small stream about 20 miles long flowing in the main on a very flat slope in a circuitous course in a gravel-filled basin. It heads in the divide between Norton Bay and the east-west portion of the Koyuk. Passes lead across this divide at low elevations. The lowest pass is by way of the branch on which camp C4 was located. At this point a broad, open saddle at an elevation of only a little more than 600 feet affords an easy route from one basin to the other. The most characteristic feature of this basin is the flat lowland through the lower three-quarters of the area and the short, rather steep gradients of the streams above the point where they enter the flats.

Tubutulik River had previously been traversed by Mendenhall and Peters, so that few notes concerning the stream arrangements were collected in 1909. In the main this basin is parallel with the igneous intrusions of the Darby Range, but above Lost Creek, where the granites disappear, the course for several miles is more nearly east and west. Above this point its general direction is north and south. In this part of its course is a lowland, locally known as Death Valley, which is elliptical in outline and about 7 miles long by 5 miles wide. North of Death Valley the headwater streams rise in the high eastern extension of the Bendeleben Mountains and flow on steep gradients into the Death Valley Basin. The lower 5 to 10 miles of the Tubutulik basin is formed by swampy lowlands similar to those at the mouth of the Kwik. In fact, the area between the lower portions of these streams is practically undivided, and it would be almost impossible to determine just what portion of the flat was tributary to one stream and what to the other.

Measured in a straight line from its head to its mouth, the Tubutulik is about 40 miles long, but its numerous meanders make the distance along the river much greater. Several low passes lie between the Tubutulik and the Kwik on the east, the Koyuk on the north, and the tributaries of the Fish on the west. The ridge between the Tubutulik and the Kwik nowhere exceeds 1,000 feet, so that at the heads of the tributaries are many places where passages at elevations of 600 to 800 feet may be found. Between the Tubutulik and the Koyuk there are two low saddles where the elevation does not exceed 1,000 feet. The most important of these saddles is the one east of Death Valley, where the trail from Nome to Candle crosses the divide. At this place the elevation is only a little more than 800 feet above sea level. The low saddle is north of the north fork of the Tubutulik and leads into Timber Creek, a tributary of the Koyuk. This pass is broadly open and has several small lakes scattered on the flat divide. Between Tubutulik and Fish rivers there are two or three low passes, but the one taken advantage of by the telephone lines is perhaps the lowest. North of this one, however, near camp C8, there is a saddle at an elevation of about 1,000 feet, by which horses can easily cross from the Tubutulik into the Fish River basin.

Southwest of the Tubutulik the Kwiniuk River drains an area of approximately 100 square miles. It has an extremely irregular course, its bends in the main being dominated by the general north-south geologic structure. It has many side streams joining it in back-hand manner. This is especially true in the portion around camp C14. About 2 miles south of this point there is a long tributary coming in from the west which makes a sharp bend and cuts across the prevailing structure to join the Kwiniuk; 2 miles north of camp C14 also there is a stream flowing almost due south until it enters the northeastward-flowing Kwiniuk. It is believed that some of these abnormal features may be explained by the obstruction of the drainage by deposits formed by valley glaciers from the Darby Range, which have prevented a former direct course to the sea.

The Kwiniuk basin is about 30 miles long and is on the whole rather narrow. In places rock walls constrict the river, but in other places there are gravel-filled basins of small extent in which the river splits into many separate channels. At the mouth, the river flows on the broad gravel deposits (which probably represent basin filling) that merge with the flats at the mouths of Tubutulik and Kwik rivers. In this part of its course the basin is characterized by an intricate network of sloughs and channels impossible to traverse in summer.

Fish River is the largest stream west of the Koyuk. Between it and the Kwiniuk many streams heading in the north-south Darby Range flow in short courses eastward into Norton Sound or westward into Golofnin Sound. Fish River, like the Koyuk, was ascended by Mendenhall and Peters in 1900, and the form of the main river has been taken directly from their map. It is an extremely tortuous stream in its lower and middle course, but in its headward part and for a short distance in the so-called Fish River gorge it is an actively degrading stream. In the lower part the river splits into numerous distributaries on the delta, and its flow is so sluggish that it is difficult to distinguish the main channel from blind sloughs. Steam river boats ascend the river as far as White Mountain, but above this point as far as Council, on the Niukluk, or as far as Mosquito Creek, on the main river, horse boats are used.

Above the junction of Niukluk and Fish rivers the valley of the main stream is constricted and the river flows through a gorge with rather steeply sloping walls for a distance of about 10 miles. Upstream from the gorge the valley opens out and the floor is a flat gravel-covered plain 15 miles wide parallel with the direction of the stream and 30 miles long transverse to this direction. This part of the basin is an unexplained physiographic feature. The plain is dotted with lakes and sloughs slightly sunk below the general level of the surface. Here and there, irregularly distributed, are low gravel mounds from 10 to 50 feet in height, that seem to mark former deposits so dissected that perhaps not one-hundredth of their original extent is preserved.

The main tributaries from the west are Niukluk and Pargon rivers. The former rises in the Bendeleben Mountains and the hills to the south about 20 miles west of the mapped area. The Pargon, sometimes incorrectly called the Parantulik, rises in the high east-west range which forms the eastern extension of the Bendeleben Mountains. It flows along the southern margin of the Fish River basin for nearly 20 miles before entering the main stream. From the east the main tributaries of Fish River are, from south to north, Etchepuk and Rathlatulik rivers and Mosquito Creek. All of these rise in the high Darby Range that forms the eastern border of the Fish River basin. In their headward portions they all flow in rather youthful valleys with fairly steep gradients, but as they cross the flats their slopes decrease, and they flow in sinuous courses slightly incised below the level of the plain.

KOTZEBUE SOUND DRAINAGE.

The only portion of the Buckland or other Kotzebue Sound drainage seen was between camps B5 and B13. In this region only the headward part of some of the streams belonging to the Buckland were observed near at hand, and therefore few additional data as to the larger features of the basin as a whole were obtained. It seems, however, that the area of this basin has been in large measure exaggerated. From the mouth of the Buckland to the divide between that river and the East Fork of the Koyuk in a straight line the distance is between 50 and 60 miles, and from the mouth to the divide near camp B5 is only a little over 60 miles.

Like many of the other basins which have been carved mainly on bedded sediments of Mesozoic age in this part of Alaska, the basin of the Buckland tributary streams shows pronounced structural control. This results in an irregular distribution of narrow valleys parallel to the geological structure of the region, with transverse gorges. In this kind of topography the recognition of the true direction of the drainage from a distance is almost impossible. The western branch of the Buckland, visible from Bear Creek (north of camp B13) flows in a broad, flat valley, the average gradient of the stream from mouth to head probably not exceeding 6 to 8 feet a mile. In the descriptions of Quackenbush[a] and of the earlier surveys by Captain Kellett and other officers of H. M. S. *Herald* and *Plover*, it is stated that the Buckland is navigable in light boats for about 60 miles as measured along the river's course, that is, as far as the forks of the stream about 20 miles north of the Koyuk-Buckland divide.

The low pass from Buckland to the east fork of Koyuk River has already been described. A pass from the Buckland into the Kiwalik basin by way of Bear Creek has been utilized by a road from the mining camp on Bear Creek to Candle. The divide between the Buckland and the Inglutalik is low, and, although usually covered with dense brush, it offers no considerable obstruction to crossing from one drainage basin into the other.

UPLANDS.

As has already been stated, the relief in the Nulato-Council region is relatively low. Few hills are more than 3,000 feet high, and the larger part of the upland is probably not more than 2,000 feet above sea level. There are, therefore, but small differences in elevation between the uplands and the lowlands and still less between different portions of the upland. This results in producing a sky line uninterrupted by any considerable inequalities.

[a] Quackenbush, L. S., Notes on Alaskan mammoth expeditions of 1907–8: Bull. Am. Mus. Nat. Hist., vol. 26, 1909.

Smooth, rolling uplands are particularly characteristic of the East Fork-Inglutalik divide. In this part of the field the features are slightly dissected, rounded domes, with gentle slopes merging with the present valley walls by a series of benches. Plate II, *B* (p. 22), shows a typical portion of this upland and is characteristic in a broad way of the divides between most of the minor drainage basins. On such uplands traveling is good, as the surface is well drained and the frost-disintegrated fragments afford good footing. Not only are uplands of this type found in the regions where unmetamorphosed sedimentary rocks form the bed rock, but they are also characteristic of parts of the schist region—as, for instance, at the head of Kwik River.

Even the higher and more rugged divides here and there show a somewhat flat-topped character. Thus, on both sides of the Koyuk-Buckland lowland there are numerous flat-topped hills, some a mile or so in width, carved on materials very different both in composition and in apparent resistance to weathering. This feature is also seen in the hills north of Death Valley on the Tubutulik. On one of these hills north of camp C7 a profile similar to figure 3 was observed which

FIGURE 3.—Profile of hill north of camp C7, at head of Tubutulik River.

showed at least five flats from a quarter to half a mile wide. These have been produced on a complex structure of schists, thin limestones, and granites.

The two main mountainous regions are (1) the divide between the Yukon and the Norton Bay drainages, called by McPherson the Brooks divide, and (2) the Darby and Bendeleben mountains. In the former the general trend is north and south, with the highest points only little more than 3,000 feet in elevation and the average much less. Conical peaks rising 500 to 800 feet above their neighbors afford easily recognizable landmarks, visible for long distances. A few steep, rocky crags were seen, but all are easily scalable. In the Darby and the Bendeleben mountains the trend of the former is predominantly north and south and of the latter east and west, so that together they form a crescentic highland area. The crest line of this range is ragged and irregular, being in places close to the north and west side of the range and at others close to the south or east side. Here and there the crest line is so narrow that passage even on foot is hazardous, and blocks of waste disturbed in passing roll hundreds of feet down the slope before finding lodgment. This is true particularly of the Bendeleben Mountains, where glacial action of the alpine type has been effective in the past. In certain parts of the Darby Range also this same agency has produced similar uplands. Plate III, *A*, shows a portion of the Darby Range much dissected by glaciation and illustrates the narrow pinnacled character of the upland that results. Such divides are not due to valley glaciers having covered the upland, but are the result of headward erosion on opposite sides of the ridge.

Regarding the origin of the uplands, there has been no clear evidence found to indicate the effective causes. As will be explained in detail later, it is known that the deformation which took place after the deposition of the Cretaceous sediments was so great that any topography formed prior to this event must have been so changed as to have little or no effect on the present topography. The surface therefore has been formed between the Eocene and the present time. It is known that none of the mountains indicated by the dips of the strata formed by the folding are preserved at the present time in this region. The upland surface has therefore been produced by erosion, and the present hills owe their height rather to greater resistance to erosion than to original constructional uplift. Whether this erosion resulted in a nearly plain surface approximately at sea level, which has subsequently been uplifted and again dissected, or whether the erosion took place at considerable elevations above sea level and leveled without base leveling the tops of the hills, is a question that must await much fuller investigation. There are the following objections to the interpretation that the present upland surface represents a formerly nearly base-leveled surface subsequently uplifted—the absence of any water formed deposits on the surface of the upland; the lack of deep-rock weathering; the number of flats separated from each other by sharp scarps similar in all characters to the uppermost one, which require similar explanations; the absence of drainage arrangement that would correspond to the hypothetical earlier surface; the indications that present-day processes are responsible for leveling without base leveling. On the other hand, the main objection to the idea that the upland does not mark an old erosion surface nearly at base level is the lack of known processes capable of producing a nearly plain surface on rocks of different resistances to erosion. It seems wise therefore to suspend judgment as to the origin of the uplands, as further information is required before their genetic classification can be effected.

COASTAL FEATURES.

Soundings made by the Coast and Geodetic Survey[a] and others have shown that nowhere in Norton Bay and Sound within the areas represented on Plates I and V is there a depth of water exceeding

[a] See chart 9380 of the Coast and Geodetic Survey, edition of 1908.

A. CHARACTERISTIC MOUNTAIN TOPOGRAPHY, DARBY RANGE.

B. EAST COAST OF DARBY PENINSULA.

100 feet, and over much of this water area the depth averages about 50 feet. In general the 5-fathom line lies several miles from the coast, so that vessels find no harbors and have to discharge cargoes on lighters. A few exceptions to this rule occur, most notably along the east side of the Darby Peninsula and at Golofnin Sound. At the former locality the coast is rocky and landing places for vessels of sea-going size are wanting. Plate III, *B*, shows a typical portion of the eastern coast with the waves beating directly on the cliffs and with a beach so slightly developed that it is impossible for a man to walk around the shore. With such topography it is evident that shelter for vessels is wanting.

Golofnin Bay, on the other hand, presents a fairly good harbor for vessels drawing less than 20 feet, as it is sheltered by high hills from the strong winds. The channel, however, is crooked and the bay is constantly filling up with the detritus brought down by Fish River. Ocean-going vessels from Seattle call at this place irregularly during the season and discharge cargoes near the mission on lighters. Without recourse to dredging, however, this harbor would be of slight value in the general economic development of the region. It is, moreover, some distance from the productive gold areas and so is not much used, although during the boom days of the Council region it gave promise of being important and even now it is the gateway by which most of the supplies for Council and vicinity enter the country.

Kotzebue Sound on the northern shores of Seward Peninsula is also a relatively shallow sea, few if any places having a depth of 100 feet. One of the latest incidents in the geology of the region was a slight depression of the land, so that the submerged lower courses of some of the larger streams afford shelter for light-draft vessels. The shallowness of the basin as a whole and the crooked and constantly changing channels leading to these harbors make navigation difficult.

Tides in Norton Sound are relatively slight in their range but increase toward the bay heads. No accurate measurements of the tides have been made in this part of the region, and as the wind has a considerable effect on the change of water surface it is impossible to make any short-period observations of value. It is probable, however, from determinations made at Nome, that the tides seldom have a range of more than 2 feet along the east side of Darby Peninsula. Judged by the way in which the Koyuk was backed up by the tide near camp A20 the tidal range near the head of Norton Bay probably exceeds 3 feet.

As has been already noted, lagoons are found along portions of Norton Sound. These owe their formation mainly to shore currents blocking the mouths of streams. Sand reefs, such as occur near Solomon and at many other places in western Seward Peninsula, are absent in the area studied. Many of the lagoons are filled with drift timber, a good deal of which has doubtless been brought down by the Yukon and cast upon the shore by the currents.

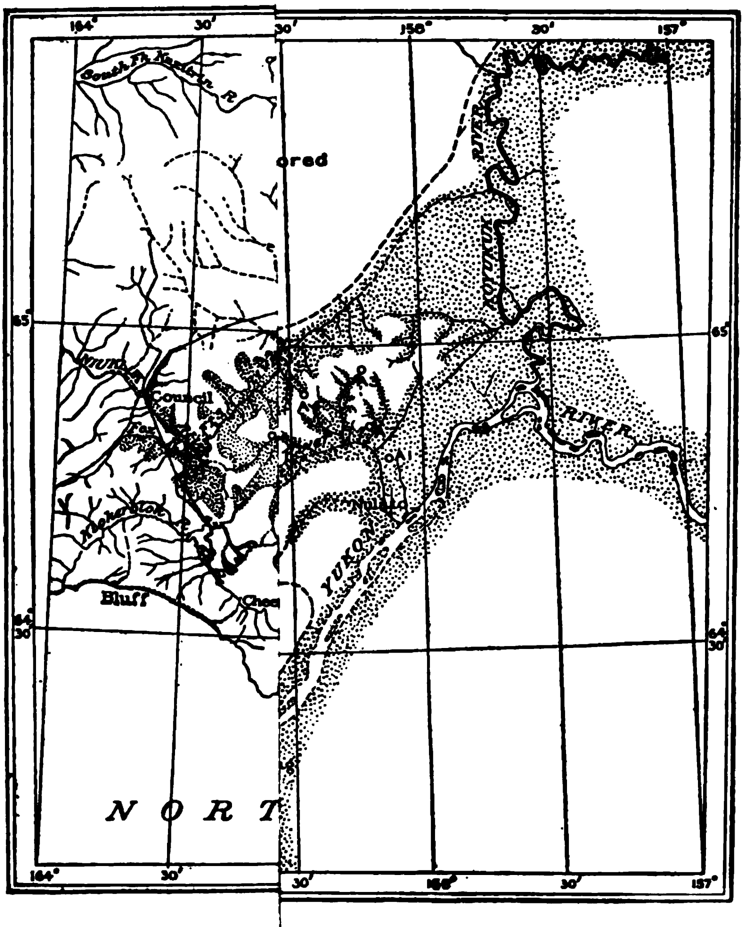
The currents are complex and have been determined mainly by the effect they have exerted on the land forms. Near the mouths of the Kwiniuk and the Tubutulik the long spits with their free ends pointing east give clear evidence that the currents there are flowing from west toward the east, but, south of camp C17 for 4 or 5 miles the apparent direction is southwest. At Carson Creek, however, the general direction seems to be northeast. On the east side of Norton Bay, near the mouth of the Inglutalik, the shore forms seem to have been made by currents flowing toward the north, whereas near Island Point the dominant current seems to divide, the southern part flowing southward and the northern part northeastward. From the south end of the Reindeer Hills the long south-pointing sand spit seems to show that the direction of currents there is in general southward.

VEGETATION AND GAME.

As the main object of the expedition of 1909 was to acquire information concerning the geology of the region traversed, little attention was paid to extraneous matters. A few notes on the general character of the vegetation and game may, however, be included.

Of the evergreen trees spruce is the only one of sufficient importance to be considered. The trees seen probably average 10 to 12 inches in diameter. Spruce extends as far west as Council, but beyond this point is practically wanting. In the eastern part of the area, near the Yukon, it grows at elevations close to 2,000 feet, but farther west, toward Norton Bay, at lower elevations, so that west of the Brooks divide it is seldom found above 1,000 feet. West of the Koyuk it rarely is found above 800 feet, and only in the valleys along the streams. In the western part of the Fish River drainage basin, spruce does not grow on any of the streams north of Mosquito Creek. Spruce is found along the eastern coast of Darby Peninsula up to elevations of about 800 feet, but west of the range it seldom grows at more than 500 feet above the sea. Plate IV shows the general distribution of timber in the region.

Birch, used by the natives for sled frames and similar gear, is found in many places in the Yukon basin, but it gradually disappears farther west until the last birch seen on the Koyuk was near Kenwood Creek and the last sizable trees in the Darby Peninsula were on the eastern slopes of Mount Kwiniuk and on the lower slopes of Mount Kwiktalik or Haystack Mountain. White birch is found in the Yukon basin, but does not occur notably to the west of this area. The Seward Peninsula birches are the yellow and the black birch. The low pros-


164°
30'
30'
158°
30'
157°
South Fk. Koyukuk R.
ored
KOYUKUK RIVER
65°
Council
Fish
Bluff
YUKON
RIVER
Nulato
64° 30
N O R T
164°
30'
30'
158°
30'
157°

trate birch, which has little or no fuel value, is much more widely distributed and can be found throughout Seward Peninsula.

Willows are common along almost all the Seward Peninsula streams. The willows are of several different kinds, from prostrate varieties to trees 8 or 10 feet in height, the latter being the main source of fuel throughout the western portion of southeastern Seward Peninsula. Alders are most numerous along the eastern shore of the Darby peninsula, where they form a dense undergrowth of half recumbent interlocking branches, through which passage can be effected only by chopping a trail.

No statement of the vegetation would be characteristic without mention of the abundant berries, which grow mainly above the tree zone. Blueberries are particularly prolific, the low bushes forming in places a mat of vegetation. Salmon berries, much prized by natives and prospectors, grow under essentially the same conditions as blueberries and are especially abundant on rolling low uplands, such as those between the Buckland and East Fork of Koyuk River. Currants are found, but are not abundant.

Several kinds of grasses and forage for horses are found and are generally sufficiently plentiful, so that they do not have to be specially sought until late in the season. The pack horses used by the Survey party were particularly fond of the so-called "goose grass," a kind of equisetum that grows on well-drained areas near the banks of the streams where trees do not form a thick shade. By the first of September frosts so impair the vitality of the grasses that forage must be sought with care in the protected valley heads facing south, and it becomes necessary to place camp with considerable thought as to the feed supply.

Flowers are abundant and give brilliancy to the landscape in the spring and summer. Some fifty varieties were noted, but no collections were made, and therefore no specific determinations were possible. The general impression, however, was that flowers were abundant, but that they were limited to relatively few genera and families.

Birds and animals are fairly abundant throughout the region, although they are not so plentiful that game can be relied on for food. In the higher hills between the Yukon and Norton Sound numerous caribou signs showed that the mosquitoes had driven these animals into the highlands during the early part of the summer. Farther west caribou are almost entirely wanting, although probably a few may still be found in the unfrequented region north of the Koyuk. Domesticated reindeer, held either by government or private ownership, are herded near the mouth of the Shaktolik and south of Cheenik. These herds are moved from place to place, and sometimes the animals stray away and become wild.

Bears are comparatively numerous in the less frequented parts of the region. Well-trodden bear trails run along the Shaktolik for many miles, where the animals fish during the salmon season. Along the ridge between Kwik and Tubutulik rivers, also, bear signs are abundant, especially while the blueberries are ripe. In the upper part of the Kwiniuk basin near camp C14 the sand bars are covered with bear trails. From the reports of prospectors and trappers it is said that most of the bears are rather large and brown, few black bears being found. The only bear that was seen by the Survey party was a very light brown.

Caribou and bear are the only two large animals in the region but there are several small animals that are caught either for their fur or as food. A few rabbits are found in Seward Peninsula, but none were seen in the Nulato-Norton Bay region. Red foxes were seen, and cross foxes are reported. Some marten, muskrat, and other small skins are taken by trappers in the Yukon basin contiguous to Nulato, but the number of skins is yearly decreasing. Porcupine were seen in the Inglutalik and Tubutulik river basins. Ground squirrels common in the less-forested regions of Seward Peninsula are almost entirely absent throughout the greater part of the area east of the Koyuk River.

Of the birds, ptarmigan are perhaps the most abundant throughout the region as a whole, but they are seldom found near the coast and are yearly becoming fewer and fewer. Early in the season these birds are found hiding in the brush with their young, but later in the summer flocks of fifteen or so may be flushed in many of the blueberry patches. After the berries begin to fail and cold weather approaches, the ptarmigan move from the higher land and congregate on the sand bars of the streams. A little later they begin to gather into the large coveys so often seen after the snow has begun to fall.

Along the coast where ponds and lagoons occur ducks, geese, and other water fowl are plentiful. The southward migration of the geese in 1909 took place the last of August and the first of September, and during this time thousands of birds passed over Norton Bay. Cranes were seen, some living on the low swampy country of the coastal plain province and others apparently making their homes on the dry rolling uplands. Robins, crows, and many other birds living in more southern regions were also observed but not minutely noted. Owls, both barred and snowy, are common, and their regurgitations may be found on almost every knob that gives a lookout over the surrounding country. A few eagles and hawks were seen. Spruce or "fool" hens were especially noted in the Darby peninsula country south of the mouth of the Kwiniuk, but they are also found in many other parts of the region.

Fish are almost always plentiful and can be relied on by travelers for food. Grayling are the most common of the fish and are found in all streams of sufficient size. In length they range from a few inches to about 20 inches. They will take a fly hook at almost all times during the summer. Trout of several varieties live in the clear swift waters of the mountain streams and may be caught with a fly hook. Salmon usually run up the larger streams and are much used for food by trappers, prospectors, and natives for themselves and their dogs. Salmon were seen on the Inglutalik as far upstream as camp B9, on the Koyuk above East Fork, on the Kwiniuk above camp C14, and on the Niukluk far above Council. The season of 1909, however, was a particularly poor salmon season, and only a few fish were caught in any of the Norton Bay streams considered in this report.

Salt water forms of life are abundant in Norton Bay and are used for food and clothing. The tomcod, a small, bony fish, and the herring are caught by natives and whites. From the fur of the hair seal much of the clothing of the natives is made, and the skin of the oogruk, a thick-skinned seal, furnishes almost all of the homemade footwear (the mukluk) of the inhabitants. Walrus is sometimes caught near the edge of the ice pack in the spring, and its flesh is used for food.

CLIMATE.

Continuous records of the various elements of climate have not been made in any part of the region for sufficient length of time to afford accurate data for describing the prevailing conditions. The nearest observation stations, at Nome and at St. Michael, are both situated on the coast and give but little information concerning the interior. At present, therefore, there are few records available for the Nulato-Council region except scanty observations extending over only short periods.

TEMPERATURE.

At Nome the highest temperature recorded during 1909 was 70° F., but it is probable that in the interior, where the temperature is not so much affected by the sea, higher records would have been obtained. The work of the Survey party was carried on in the higher hills during the hottest part of the summer, so that the temperatures were much lower than they would have been near sea level. Ice one-quarter of an inch thick formed on water in a pail during the night of July 24 at an elevation of about 1,500 feet at camp B5. On August 5 ice remained on the small pools of water along Peace River at an elevation considerably less than 1,000 feet until after 10 a. m. The hills north of Mosquito Creek and the head of the Fish River valley were heavily covered by snow on September 1, and on September 16 snow covered the ground down to 800 or 900 feet on the southern end of the Darby Range and remained on hills above 1,000 feet for the rest of the season.

The mean annual temperature at Nome for 1907 was 24° F., and for 1908 it was 25° F. As it seems fully as warm at Nome as in the region to the east at the same time, it is probable that the mean annual temperature is not far different for the two localities. The summer temperatures are higher in Nulato-Council region because of the absence of sea control, which would also make the winter temperatures lower, so that these two factors would tend to balance each other. Further data on the temperatures are afforded by a few observations made at Nulato and at the Omilak silver mine, and published by Abbe.[a]

Extreme ranges in temperature (°F.) at Nulato and at Omilak mine, Alaska.

	Jan.	Feb.	Mar.	Apr.	May.	Oct.	Nov.	Dec.
Nulato:								
Maximum	23	29	44	50	71	47	28	31
Minimum	−62	−60	−33	−23	7	−13	−36	−54
Omilak mine:								
Maximum	43	36	43	55	63	36	32	....
Minimum	−33	−52	−36	−24	16	−2	−29	−29

The observations at Nulato from which this table was compiled were carried on for 12 months, from October, 1894, to May, 1895, and from January to April, 1896; those at Omilak mine were also carried on for 12 months, from January 2 to May, 1884, from October 18 to December, 1884, and from January to April 16, 1885. In the report it is noted that in the fall of 1894 the Yukon was closed at Nulato on October 16, and opened in the spring of 1895 on May 22. Near Omilak mine, Fish River opened on May 21, and was closed by ice on September 25, 1884; in 1885 this river opened on May 9.

Dall,[b] who spent a winter at Nulato, has published the following table of temperatures for the different seasons at that place:

Range of temperature at Nulato, Alaska, by seasons.

	°F.
Spring	29.3
Summer	60.0?
Fall	36.0?
Winter	−14.0
Year	27.8

PRECIPITATION.

During the summer of 1909 the precipitation in the western part of Seward Peninsula was abnormally low, and it seems probable that

[a] Abbe, Cleveland, jr., Prof. Paper U. S. Geol. Survey No. 45, 1906, pp. 133–200.

[b] Dall, W. H., Alaska and its re[illegible] [illegible]

the amount of rain received by the Nulato-Norton Bay region was also less than usual. There were less than a dozen really rainy days from the latter part of June to the end September, but in this period there were 38 days on which it showered.

The following table gives the results of previous instrumental observations at Nulato and at the Omilak silver mine.[a]

Mean precipitation, including melted snow and mean number of days with days with 0.01 inch or more precipitation at Nulato and Omilak mine, Alaska.

	Jan.	Feb.	Mar.	Apr.	May.	Oct.	Nov.	Dec.
Nulato:								
Mean total	0.68	0.91	1.46	0.16	0.36	1.36	1.20	1.42
Days	5	7	12.5	2	4	8	6	8
Omilak mine:								
Mean total	0.40	0.32	0.15	0.07	0.02	0.23	0.45	0.18
Days	3	3	3.5	4	2	....	3	3

The record for Nulato was for 10 months, from October, 1894, to May, 1895, and from January 3 to March, 1896; the record for Omilak mine was for 9½ months from February to May and from October 18 to December, 1884, and from January to March, 1885.

From what is known of near-by areas, it may be stated that the amount of precipitation during the 8 winter months is roughly between one-half and one-third of the total for the year. If a factor of this value be applied to the tables so as to correct the total for the year on the basis of the entire 12 months, it follows that the annual precipitation at Nulato is between 15 and 20 inches and from 10 to 12 inches at Omilak mine. This would make the Fish River region about equivalent in moisture to the region near Nome and the region around Nulato much more moist. The region as a whole, however, would be classed as semiarid and similar to a large part of the States of Montana, Idaho, Wyoming, and Colorado. As the larger part of the precipitation comes from June to September, the impression gained by a summer traveler is of a region of much greater rainfall than is actually the case.

WIND.

Throughout the region the northerly winds are the fair weather winds, whereas those from the south usually bring rain. During 1909 the predominant wind direction was from the north, and the weather was accordingly dry for the greater part of the time. Owing to the absence of a heavy cover of vegetation over most of the upland area, the force of the winds is strong and the effects are marked. On the bare limestone hills pieces of detritus are moved by the wind, and the small sand grains are quickly removed from the places where

[a] Abbe, Cleveland, jr., op. cit., pp. 162–165.

they are formed by disintegration. In many places the foliage on the lower lands is covered with the wind transported dust.

Dust whirls caused by convectional currents of air induced by overheating the lower layers were seen several times along river bars. One such whirl started on the Shaktolik River with such explosive violence that it threw up sun-baked pieces of mud several inches in diameter and scooped out a shallow depression. Several dust whirls were noted on the lower part of East Fork and Koyuk rivers and could be traced for several miles across country.

SETTLEMENTS AND POPULATION.

The only villages in the Nulato-Council region are Nulato, Kaltag, Cheenik, Bluff, and Council. Road houses are, however, numerous along the coast and form a complete line from east to west. During the summer there is but little travel, but during the winter the mail and travelers furnish patronage to road houses along the coast at Carson Creek, Walla Walla, Kuiuktulik, Miniatulik, Moses Point, Isaacs Point, Ungalik River, and Shaktolik River. Along Fish River there are road houses between Cheenik and Council, at the mouth of Fox River, and at the mouth of the Niukluk. On the Yukon River are numerous road houses from Kaltag eastward.

A few scattered cabins are the only other habitations in the region, and these are occupied but a short time each year, mainly by trappers. On the lower part of the Inglutalik, 6 or 8 miles from the coast and on this same stream near camp B7, are cabins of this sort.

The mining and prospecting centers of settlements are principally in the vicinity of Bluff and Council on Ophir, Melsing, Mystery, and Goldbottom creeks. There are several cabins, however, on Bonanza Creek occupied by placer miners who hold ground on this stream. At the Omilak silver mine on Omilak Creek, a tributary of Fish River, a mining camp has been established since the early eighties and, although now practically abandoned, at different times has had more than a score of inhabitants. On Bear Creek, a tributary of the Buckland from the west, there has been a small settlement of placer miners since 1902. Two cabins near Alameda Creek, a tributary of Koyuk River from the west, mark a small placer settlement. Ditch camps with one or two men each have been established along the Candle ditch line on Kiwalik River, but are vacant during the winter.

Native encampments are found principally along the coast and belong almost entirely to Eskimos. Along the Yukon are Indian villages, generally established on the outskirts of the white men's villages. The Indians, as a rule, have a more or less permanent abode, but the Eskimos migrate along the coast and are seldom found several seasons in the same place. There is an exception, however, in the case of those owning reindeer. These people usually summer in nearly the same place, but during the fall and winter they are constantly moving their herds from one pasture ground to another. The largest reindeer settlements are near Shaktolik and Cheenik, where the Government herds are located. These herds are mainly tended by natives.

No attempt was made to obtain a count of the population, but, from the best estimates it has been possible to make, it is probable that there are between 1,000 and 1,500 whites and natives in the Nulato-Council region.

DESCRIPTIVE GEOLOGY.

In the Nulato-Council region there are two major geologic provinces, namely, the Cretaceous basin and its inclosing rim. In the mapped area only portions of the western borders of the basin were studied, and neither the northern nor the southern boundaries were determined. In the Cretaceous areas only exploratory surveys were made, and the eastern rim was not visited by the party of 1909. By reason, therefore, of the relatively slight amount of geologic information, this field is shown on the comparatively small scale map, Plate V (in pocket), of the Nulato-Norton Bay region. Farther west, however, the previous work of Mendenhall, Moffit, Collier, Brooks, and Richardson, supplemented by the surveys of 1909, has warranted publication on the larger scale of Plate VI (in pocket), the geologic map of southeastern Seward Peninsula. It should be pointed out that neither map presents the details of the geology, for there are many problems which must await much more searching investigation than the hasty trip of 1909 would permit.

The rocks or deposits of the region may be assigned to six main groups—the undifferentiated metamorphic rocks mainly of pre-Silurian age, the Paleozoic rocks, the Cretaceous sedimentary rocks, the igneous rocks mainly pre-Cretaceous but in part later than that period, the veins, and the unconsolidated deposits mainly of Quaternary age. Each group shows individual characters which are described in the following pages and the areal distribution is indicated on the geologic maps, Plates V and VI. Plate VI is the more serviceable for showing the distribution of the metamorphic and igneous rocks, and Plate V for showing the nonmetamorphic consolidated sediments, but both maps are necessary for a complete idea of the areal extent of the different geologic members.

UNDIFFERENTIATED METAMORPHIC ROCKS.

The greater part of southeastern Seward Peninsula and the southeastern part of the Nulato-Norton Bay region are formed of a series of metamorphic rocks, much folded, sheared, and so changed that in but few places are their original characters preserved. This complex consists of a variety of different rocks grouped on the basis of structure or lithology as schists, limestones, and quartzites.

AREA EAST OF THE YUKON.

The eastern area of metamorphic rocks has not been studied in detail, but the following quotation from Maddren [a] will serve to describe the general lithology:

> The oldest group of sedimentary rocks consists of the quartzite and mica-quartz schists, with associated crystalline limestones, garnet schists, and fine-textured slaty schists or phyllites that form a large part of the Kaiyuh Mountains and extend northeastward across the Yukon to the basin of Tozitna River and possibly southwestward to the Halditarod. Succeeding this belt of schistose sediments is an extensive group of ancient diabasic effusive rocks that appear to be stratigraphically associated with the schistose rocks. These diabasic rocks have not been deformed nearly so intensely as the schistose group. In places they show greenstone schist phases, but for the most part they have not been greatly altered. Their contact relations to the schists are not known in this region. They appear to flank both the northwest and the southeast sides of the schist belt in the Kaiyuh Mountains, where they extend southwestward to the Innoko, and they have extensive development toward the northeast north of the Yukon as far as Gold Mountain and beyond. No statement as to the thickness of this diabasic group can be made at present.

SOUTHEASTERN SEWARD PENINSULA.

CHARACTER AND DISTRIBUTION OF METAMORPHIC ROCKS.

The schists form the greater part of the metamorphic complex and may be described according to the mineral or minerals characteristic of them. The schists most commonly found are quartzose, graphitic or carbonaceous, biotitic, feldspathic, and calcareous. Gradations between different types are frequent and the differentiation is by no means certain. It appears, however, that the present lithologic differences are in considerable measure due to original characters, so that in a broad way identity of lithology may be taken as indicating deposits formed at essentially the same time. This is generally true of the graphitic schists, is sometimes true of the calcareous schists, and is seldom true of the biotite schists.

Owing to the complexity of structure and the insufficient examinations of parts of the field, it has not been possible to indicate on the map consistently the areas occupied by the various types of schist. It has been found necessary to show areas which, for want of a better name, have been called "undifferentiated metamorphic rocks." These undoubtedly contain representatives of some of the rocks that have

[a] Maddren, A. G., Innoko gold placer district, Alaska: Bull. U. S. Geol. Survey No. 410, 1910, p. 43.

been differentiated as well as others, but, as stated above, either the scale of the map or the absence of definite data has precluded accurate mapping. In a measure the lumping together of diverse units has obscured geologic relations, and on the map it frequently happens that the undifferentiated metamorphic rock symbol terminates some other symbol in an abnormal manner. As a specific instance of this kind may be cited the region for 10 miles north and west of Bluff. Detailed traverses along the western margin of this area showed the presence of the feldspathic schists of igneous origin, but no other data are available south of Fox Creek, except in the immediate vicinity of Bluff. Therefore, although it is probable that much of the region is of the feldspathic schist type, it seems unsafe to map the distribution in this 100 or more square miles on such slight evidence. Thus at the risk of obscuring the important fact that the feldspathic schists along the western margin of the map are continuous with the feldspathic schists of the Bluff and Fox Creek regions it has seemed best to adopt the more noncommittal course of showing that the rocks have not been adequately differentiated.

As shown in Plate VI there are five main areas of undifferentiated metamorphic rocks—(1) around Kwik River, (2) between the two lava flows north of the Koyuk, (3) the Bendeleben Range from the head of Death Valley westward, (4) the western part of the mapped area south of the Niukluk, and (5) along the western flanks of the Darby Range extending southward across the head of Kachauik River to the coast of Norton Bay east of Bluff.

KWIK RIVER AREA.

The schist area at the head of Kwik River shows few exposures in place, and practically nothing was learned regarding the structure and relationship of the rocks of the region except that they are quartzose schists. Toward the east or near the limestone area at the head of Kenwood and Mukluktulik creeks the schists are predominantly very dark and somewhat graphitic, and the rocks may be the equivalent of some of the black slates and quartzites found in places intimately connected with dark limestones. Farther west, however, the similarity to the carbonaceous schists is not so marked, and it is possible that one of the other types of schist is represented.

This schist is highly quartzose in all places, contains some chlorite, practically no garnet or feldspar, and few specimens of it effervesce with acid. Numerous cubical cavities show that it contained pyrite in considerable amounts. It finds topographic expression in a series of massive, slightly dissected hills with gentle slopes covered with waste and devoid of outcrops. Owing to the absence of structural determinations no statement can be made of the thickness or relations of the member. Looked at in detail, however, the minor structures show that the rocks have been so deformed that schistosity has been produced throughout. On the flat-topped, massive hill east of camp C4 the float shows in almost all instances clearly marked evidence of two structures—that is to say, the plication of a previously developed cleavage and color banding. As this structure was not seen in place, however, the relation of the two structures in age could not be determined. The only fact bearing on this point is the occurrence of a shattered anticline west of camp C3, the axis of which strikes northwest-southeast and pitches strongly to the northwest.

AREA NORTH OF THE KOYUK.

The area of undifferentiated metamorphic rocks north of the Koyuk was not visited by the party of 1909. From the manuscript notes of Moffit, who studied the region in 1903, it is evident that a number of different types of schist were found. East of Kiwalik Mountain black slates and carbonaceous schists are closely associated with the limestone area. As the granite contact of Kiwalik Mountain is approached biotite forms an important constituent, although it is of no stratigraphic significance, as it is undoubtedly due to the intrusion of the granite. West of Kiwalik Mountain the schists, according to Mendenhall's field notes, are mainly calcareous; with some greenish schists which may correspond to the feldspathic schists to be described later. Quartz-chlorite schists are abundant in places, but their stratigraphic position, with respect to the others, has not been determined.

BENDELEBEN MOUNTAIN AREA.

According to the geologists who studied contiguous areas in 1900, the metamorphic schists of the Bendeleben Mountains were considered distinct from the other schists of the region and were therefore given a name and assigned to a more or less definite stratigraphic position. In 1908 the senior writer of this report made a cross section of the range along the western margin of the area, and in 1909 the party had the opportunity of studying the section north and west of Death Valley, where rocks previously considered as belonging to the Kigluaik group are exposed. These studies have caused considerable doubt as to the desirability of retaining the stratigraphy as outlined formerly, and these rocks will therefore be treated as "undifferentiated metamorphic rocks."

Mendenhall[a] mapped the Bendeleben Range as two large areas of massive intrusives, mostly granite, with a metamorphic series sep-

[a] Mendenhall, W. C., A reconnaissance in the Norton Bay region, Alaska, in 1900, a special publication of the U. S. Geol. Survey, 1901.

arating the two. In the text the following statement[a] of this schist area is made:

About the head of Fish River the mountains are chiefly granitic, but along their flanks and sometimes extending through them in belts of varying breadth which mark the passes are areas of schistose sediments.

About a mile above the camp of July 20 along the creek is an outcrop of a rusty and very graphitic schist associated with more calcareous phases. Five miles farther along the right bank of this same branch of Fish River is an outcrop of bluff slates with very little calcareous matter, while 2 miles farther northwest in a gap between two branches of Fish River the series is represented by a white, coarsely crystalline marble. This narrow belt of the crystalline series between two great intrusive granitic masses expands to the northwest.

Collier[b] states in a report published in 1908, the field work for which was completed in 1903:

The only section across the Bendeleben Range which has been examined by the writer is along Parantulik (Pargon) River and Ella Creek, between the heads of which there is a low pass. The structure here appears to be anticlinal and the prevailing rocks are dark-colored quartz-biotite schists and gneisses similar to those of the Kigluaik Range. Sills and dikes of coarse-grained granite or pegmatite are also present. White crystalline limestones containing scattered grains of graphite occur in beds 20 feet or more in thickness interbedded with the schists along Parantulik River from a point near its head to the edge of the Fish River lowland.

Smith in 1908 studied a section along the upper Niukluk across the range to the northern margin. The examination showed that the section was composed of quartzose schists, a few much dislocated limestones, a complex and very numerous series of granitic intrusives, and black carbonaceous slates and schists. All of the rocks were highly biotitic. North of Birch Creek black slates and calcareous schists predominated. All the rocks were much sheared and original structures were not discoverable, but the diversity of trends of the cleavage noted were such as to lend but slight support to the idea that the structure is in general east and west.

The observations of the party in 1909 in the Bendeleben Range were confined to the extreme eastern part and consisted of a study of the 2,200-foot hill northwest of camp C7, and of the 3,000-foot hill north of camp C8. On the first traverse were found biotitic schists with some thin limestone members and greenstone schists, all thoroughly cut up by granitic intrusions of later date. On the second traverse the same kinds of schists were also found, but in addition there were some carbonaceous schists and greenstones were more abundant.

[a] Op. cit., pp. 200–201.

[b] Collier, A. J., and others, The gold placers of parts of Seward Peninsula, Alaska: Bull. U. S. Geol. Survey No. 328, 1908, pp. 67–68.

Southwest from camp C8 to C9, 3 or 4 miles from camp C8, the schists are not much intruded by granites and belong almost entirely to the group of feldspathic schists with here and there a few limestones and a little black slate. These schists appear to be fully as metamorphosed as those to the north and strongly suggest a trend more nearly north and south than east and west.

On account, however, of the small amount of investigation in the larger part of the Bendeleben Mountains it seems unsafe to differentiate the schists on the map. They are characterized as a whole by the presence of biotite, but this is of late origin and is not stratigraphically significant. Otherwise all the various kinds of schists and other metamorphic rocks have been recognized, and the series therefore can not be regarded as a unit.

AREA SOUTH OF THE NIUKLUK.

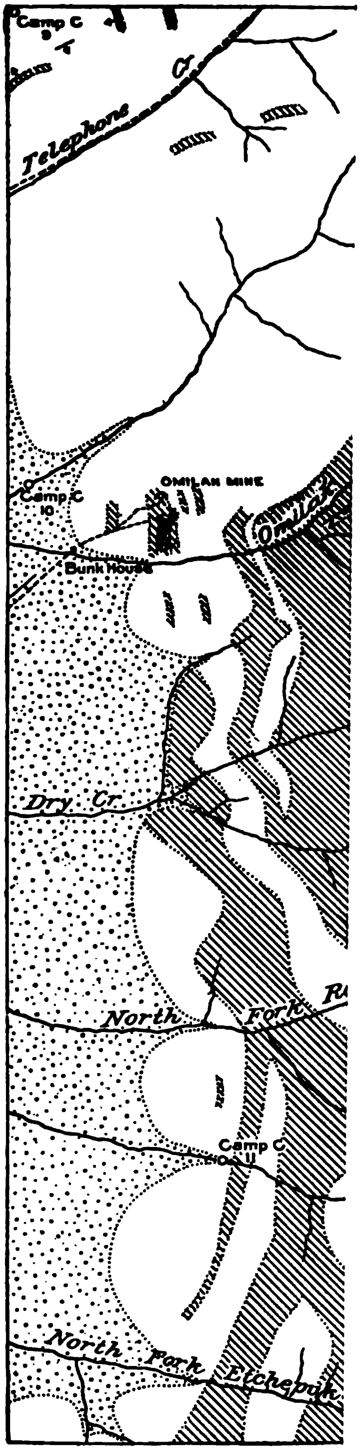
The undifferentiated metamorphic rocks along the western margin of the mapped area south of the Niukluk have been studied in detail where they enter the Solomon and Casadepaga quadrangles. From this study it was determined that the schists were mainly of the quartz chlorite type and that they underlay the limestone near the head of Fox Creek. North of the Niukluk, however, younger schists, called in the region to the west the Puckmummie schist,[a] consisting mainly of black slates and thin limestones, probably overlie the limestone. These rocks seem to merge with the black slates that form the southern flanks of Mount Bendeleben and would indicate enormous deformation not recognizable by surface features.

West of the belt of greenstone schists the rocks show many different lithologic types, but black quartzitic schists, quartz chlorite schists, and calcareous schists predominate in such complex relations that no separation of them has been made. Undoubtedly some of the quartzose schists correspond to the older schists to the west, but some are the sheared equivalents of the heavy limestones and others may belong to the black slate series, which will be described later. In the southern part of this western area a large part of the undifferentiated metamorphic series is the equivalent of the greenstone and feldspathic schist series, but this part has not been closely examined.

AREA WEST OF THE DARBY RANGE.

The fifth large area of undifferentiated metamorphic rocks is along the western flank of the Darby Range and extends southward along the head of Kachauik Creek to the coast west of Rocky Point. In this area schists of a great variety of lithologic types are found in such intricate interrelations that considerable generalization is re-

[a] Smith, P. S., Geology and mineral resources of the Solomon and Casadepaga quadrangles: Bull. U. S. Geol. Survey No. 433, 1910, pp. 62–66.


Camp C 9
Telephone Cr.
Camp C 10
OMILAK MINE
Omilak
Bunk House
Dry Cr.
North Fork R
North
Camp C 11
North Fork Etchepuk

quired in mapping them. Plate VII shows a part of this region south of the Omilak mine on a scale of 2 miles to the inch and indicates the geology in some detail. For the present the main interest in this map centers in the arrangement of the various schist and limestone bands. Even on this larger scale map, however, it is impossible to show the actual complexity of the geology. Schists of many different lithologic characters are found in the area covered by this map, but practically all of them are more or less biotitic. Some carbonaceous schists and quartzites suggest the presence of younger members of the schist series, whereas the relations of others show that they are older than the limestones which are believed to be higher in the series.

In the undifferentiated schist area at the head of Kachauik Creek the schists are biotitic, chloritic, and sometimes calcareous, and discrimination of the various types is impossible with the poor exposures. Southward, however, schists lying below the limestone at White Mountain have been recognized by Mendenhall and Collier on Fish River. Similar schists extend southward and probably form most of the hills in the low divide between Norton Sound and the Golofnin Bay drainage. Unfortunately, however, this area has not been studied in detail and the differentiation of the rocks must await further investigation.

SUMMARY.

The undifferentiated metamorphic rocks are highly sheared and cleavage is the dominant structure observed. In many parts of the field the cleavage is at a low angle. In many outcrops where an earlier structure is recognizable the two structures do not coincide, and it is believed that this is the general rule. Faulting is also common in the schists, but the amount of dislocation is generally not determinable on account of the absence of clearly defined horizon markers.

In the typical schist areas where igneous intrusions have not afforded more resistance to erosion, the topographic forms produced are smooth and rolling. Characteristic schist topography is dominant in the eastern part of the Kwik River Basin and is typical of a considerable part of southeastern Seward Peninsula. Here and there on the summits of the ridges rocky knobs of irregular form rise 10 to 30 feet above the surrounding uplands. In the mountainous regions the schists form rugged hills with steep slopes. As a whole, however, the schists are less resistant to erosion than the limestone or igneous rocks and are therefore found in the lower land and passes.

Intrusive activity of several periods has affected the undifferentiated metamorphic rocks. Greenstones, granites, diorites, and other igneous rocks cut these schists and have each had a share in the metamorphism and obliteration of the original characters and distribution of the schists.

As the undifferentiated schists as mapped include several stratigraphic units of different origin, form, and age, no general statement can be made of the relation of these rocks to the others of the region. It is clear, however, that some of these schists are older than the limestones and other rocks which will be described later, for they underlie them. The question of age and relationship will be discussed more fully in the section on historical geology. For the present, however, it seems justifiable to state that, taken as a whole, the area of undifferentiated metamorphic rocks is composed of rocks older than any of the other areas indicated on the map and is chiefly pre-Silurian.

PALEOZOIC ROCKS.

There are five main areas of rocks which are presumably of Paleozoic age, and, although more detailed investigation will undoubtedly show that parts of the undifferentiated metamorphic rocks are of similar age, the lack of information and the complexity of the structure forbid closer correlation at this time. Characteristically all the known Paleozoic rocks are metamorphosed and lithologically consist of limestones and schists complexly folded and faulted. As indicated on the map (Pl. VI), these five areas are as follows: The ridges east of the Darby range extending from the coast of Norton Sound on the south to beyond the Koyuk on the north; the hills east and west of the Fish River gorge from the head of Kachauik Creek to Ophir Creek, including the limestone hills on Fish River near White Mountain; the region south and east of the Omilak mine; the area exposed on the seacoast from Bluff to Topkok Head extending inland an undetermined distance; and the hills at the head of the Mukluktulik. In addition to these larger areas there are smaller areas, some shown on the map and others included in the undifferentiated metamorphic rocks.

AREA EAST OF THE DARBY RANGE.

Along the eastern flank of the Darby Range a group of rocks, consisting mainly of limestones with some schistose bands and closely associated with black slates and quartzites, was noted by Mendenhall in 1900, and studied in some detail by the survey party in 1909. This belt extends from the seacoast with a general northerly trend across Kwiniuk River and along the Tubutulik, forms the eastern divide of Death Valley, and is exposed north of the Koyuk in the hills east of Kiwalik Mountain. Although it probably extends still farther north, its obvious continuation ceases at this place. In this distance the average width of the belt is from 4 to 6 miles. Capital

A.

B.

PALEOZOIC LIMESTONE, DARBY PENINSULA.

A, Intruded by greenstone; *B*, Intruded by granite.

exposures are afforded along the seacoast from the mouth of the Miniatulik southeast nearly to Carson Creek. Studied in detail, the exposures show a great thickness of limestones, considerable dolomite, black carbonaceous slates, and schists, all cut by greenstones, granites, and diorites.

The limestones are in places grayish blue but in other places nearly black. Associated with them in such intimate and complex relations that they can be separated only by refined investigation are dolomites usually of a light-gray, slightly pinkish color. Light-colored dolomites have been recognized in the sea cliff exposures, in the hills between the Kwiniuk and the Miniatulik east of camp C15, and in the hills near camp C5, and east of Death Valley. No measurement of the thickness has been made, but it seems certain that not less than 1,000 feet are required to account for the field distribution.

Although highly metamorphosed, poorly preserved fossils were found in the light-colored dolomite 2½ miles east of camp C15 on Kwiniuk River. According to Kindle, who examined the collection—

Lot 9AS130, locality 9AS180, Kwiniuk divide, is represented by a single specimen. This is the now well-known though undescribed thick-shelled lamellibranch which has generally been compared with *Megalomus canadensis.* This fossil indicates a late Silurian age for the bed from which it comes. It is interesting to note that it occurs here as at White Mountain (and at the Ramparts of the Yukon) in a highly magnesian limestone. The indexical value of this fossil rests upon our knowledge of its faunal associations in southeast Alaska, where it occurs in association with various late Silurian fossils.

At this place the areal relations are indeterminate. There is some very dark-colored limestone which seems to be either a thin band between two dolomitic bands or else unconformably overlies the dolomite. Northward, however, near camp C5, at the head of Lost Creek, the dolomite lies to the east; that is, apparently on top of the dark limestone. This may be due to intense folding or faulting, or it may be normal depositional sequence.

The limestones associated with the Silurian dolomite range in color from light bluish gray, nearly white, to dark gray, almost black. They are exposed at a number of places in the mapped belt, but the most significant outcrops are those found in the divide between the Kwiniuk and the Tubutulik and along the coast from camp C16 to camp C19. In all places the limestone is folded and contorted with many faults and with calcite and some quartz veins. It has been intruded by greenstones, granites, and diorites. Plate VIII, *A* and *B*, show exposures of these limestones in the neighborhood of the intrusions and afford a fairly good idea of the general characters. Plate VIII, *A*, especially shows the well-marked bedding of the limestone, emphasized by the alternation of bands of light and dark colored limestone. Plate VIII, *B*, shows a more schistose phase, with the bedding marked by the color banding particularly evident in the right-hand portion.

At many places along the sea cliffs poorly preserved fossils were found, and, although none of them was sufficiently perfect or distinct to permit specific determination, there seems to be no question that they represent a higher horizon than that of the dolomite already described. According to Kindle, who examined the collections, a Devonian or Carboniferous horizon is represented, and in his opinion the higher rather than the lower portion is more probable. Ulrich, who examined the fossils hastily, also agreed with the probable Devonian or Carboniferous determination, but appeared to think the lower rather than the higher position was the more probable. There does not seem, however, to have been any marked difference between the amount of metamorphism or deformation undergone by the Silurian and the Devonian-Carboniferous rocks.

In the limestone hills south of the Kwiniuk River conditions similar to those noted on the coast were observed, and it is evident that the same group of rocks is represented. The higher hills are usually formed of limestone, but the saddles are here and there formed of feldspathic schists presumably of later origin. Owing to the scale of the map it has not been practicable to indicate these later schists except in a most general way, but it should be stated that these schists and greenstones are principally of igneous origin; they are not included in this group of sedimentary rocks, but will be described later under the igneous rocks.

In the region between the coast and Kwiniuk River there are, however, slates and schists of sedimentary origin which at the present time are not to be separated from the Paleozoic limestones already described. The precise relation has not been satisfactorily determined and fossils have not been found in them. There is small reason, however, to doubt that they are closely related to the Devonian-Carboniferous group.

These schists and quartzitic slates are perhaps most extensively exposed in the upper part of Mount Kwiniuk, but their structure and other characters are most clearly seen in the coast section. Usually these rocks are of a black color due to the presence of finely divided carbonaceous matter which, in some places at least, is graphite. The rocks are very quartzose and are low in other minerals. Cleavage is commonly developed, but schistosity is not so pronounced as in the older schists. Apparently schistosity is more common in the less quartzose parts of the rock. In the normal quartzose phases the rock has fractured and has had jointing developed, which causes the rock to disintegrate into a talus of small rectangular blocks. No measurements of the thickness of the slate-schist member were obtained, but it must be at least several hundred feet.

From the foregoing description, it is evident that a large mass of Paleozoic sediments which have undergone more or less fully the same general history lies east of the Darby Range. These rocks, which are complexly folded, faulted, and metamorphosed, consist mainly of dark-colored limestones with subordinate thicknesses of dolomite, black slates, and schists. They are cut by intrusives of greenstone, granite, and diorite and in age include members ranging from Silurian to Devonian or Carboniferous, with neither the overlying nor the underlying rocks exposed in close relationship. They have a thickness of at least 2,500 feet and, if considerable reduplication has not occurred, their thickness possibly exceeds this amount many times. They form bold prominent hills with scanty vegetation, covered with an angular frost-riven talus of float, and are widely developed throughout Seward Peninsula.

FISH RIVER AREA WEST OF KACHAUIK CREEK TO OPHIR CREEK.

In the hills east and west of the Fish River gorge from the head of Kachauik Creek to Ophir Creek, including the limestone hills on Fish River near White Mountain, is an area of Paleozoic rocks to be correlated with the rocks of the Kwiniuk region. The most definite data regarding the geology of this field are afforded by the exposures near White Mountain. Fossiliferous beds were found here by Mendenhall in 1900 and have been further studied by Collier, Hess, Kindle, and Smith, but were not visited by the party in 1909. In the description of the exposures on the lower Fish River it will not be possible except at great sacrifice of brevity to credit the particular contributions of each of the different geologists, but it may be remarked that the present writers are acting more in the rôle of compilers than contributors.

Three miles southeast of White Mountain micaceous, highly metamorphic schists dipping north underlie, probably unconformably, the rocks farther up the river. There is a considerable area of river flood plain in which exposures are lacking, and then come white dolomite hills from which the settlement of White Mountain is named. The dolomite is lithologically identical with the dolomite of the Kwiniuk region, and furthermore contains the same thick-shelled lamellibranch (*Megalomus canadensis*) together with certain other Silurian forms; the correlation seems therefore well founded. Less schistosity has been developed in the dolomite than in the rocks to the southeast, and for that reason there is believed to be an unconformity between the two.

Farther upstream and—if the apparent structure of the rocks is the true structure—overlying the dolomite is a series of schists. Considerable doubt is felt as to the relation of these schists, and it has been deemed expedient in this report to place them among the undifferentiated schists rather than to express their possible correlation with the Paleozoic black slate of the Kwiniuk region, though the latter is by no means impossible. Still farther upstream near the point where Fish River makes an east-west bend south of Steamboat Slough fossil corals have been found in a nearly black limestone. This limestone is lithologically identical with the black limestone of the Kwiniuk locality, and the fossils have been determined to be analogous. As a whole the rocks on lower Fish River are less metamorphosed than in the Kwiniuk region. Near the black Devonian or Carboniferous limestone are black graphitic slates the relation of which is not determinable, but they seem to be lithologically similar to the slates on Mount Kwiniuk in the more eastern locality.

Along the divide between the Fish River lowland and Golofnin Sound from camp C23 west to the head of Mystery Creek limestones with black slates form the country rock. None of the beds, however, were recognized as dolomitic. As a whole the rocks from camp C23 to Fish River are more schistose than their equivalents at White and at Black mountains, but the dominant north-south trend seems to be strong reason for connecting the rocks at the two places. Apparently, the dip of these beds east of Fish River is to the west at rather high angles, but original bedding is seldom recognizable, and the occurrence of diverse dip at places where the two structures have been determined points strongly to the conclusion that the great thickness represented by the surface exposures is due to reduplication through folding.

West of Fish River gorge the schistose character of the limestones is less pronounced, the rock becomes more massive and, although shattered and deformed, shows not much cleavage and but few secondary minerals. Immediately beneath the limestone at the head of Mystery Creek lies a considerable thickness of black quartzitic and graphitic slates. These have not been adequately differentiated in the field, and it is probable that part of the undifferentiated schists on Melsing Creek may belong to the same schist series as those in the Kwiniuk region, for black graphitic slates closely associated with limestones are known to occur at many places in the basin of this stream.

Whether the Paleozoic rocks extend northward across the Fish River flats and are represented by the limestone-slate group at the head of Fish River and Boston Creek has not been definitely proved. It is assumed, however, in the absence of conflicting evidence, that the two areas are the same, and it is on this basis that they have been represented by the same pattern on the geologic map (Pl. VI). According to Mendenhall's field notes the eastern part of this area

WESTERN FLANKS OF DARBY RANGE.

A, Limestone and schist at Omilak mine; *B*, General view from south.

consists mainly of white crystalline limestone associated with graphitic and rusty schists. So far as his records show, the predominant dip is to the west and the strike northwest.

In 1909 F. F. Henshaw traversed the lower slopes of the hills north of the Fish River lowland from Pargon River as far east as Boston Creek and the geology for that part of the range is represented according to his observations and is only approximate. Whether this belt of limestones may not continue still farther north across the range is not known because of the absence of any field investigation. Although such an interpretation is probable, it has been deemed expedient to truncate abnormally the Paleozoic pattern by representing the northern part of the range as formed of undifferentiated rocks.

In the vicinity of the mountains the Paleozoic rocks are cut by granite dikes and are locally as well as dynamically metamorphosed. South of the Fish River lowland the Paleozoic rocks are also cut by granites and in addition are intruded by greenstones. The latter undoubtedly would be found in the northern area also if more of the region had been examined. It should be noted that where mica-like minerals occur in the Paleozoic rocks near the granitic intrusives the mineral is usually biotite, whereas in the parts remote from the influence of the granite the mineral is chlorite, and biotite is absent.

OMILAK MINE AREA ON WEST SLOPES OF DARBY RANGE.

East of the area of Paleozoic rocks just described there are limestones which resemble in many features those of the Kwiniuk region, and although the correlation is by no means conclusive, it is the closest that can be made with the data now available. No fossils have been found in these rocks and their structure is so complex that any relation between the various units may be postulated. The correlation between the limestones east and south of the Omilak mine has been based almost entirely on lithologic evidence. The geologic map of the Omilak region (Pl. VII, p. 45) shows the distribution of the rocks in greater detail than the general geologic map (Pl. VI). Even this scale, however, fails to express the complex character of structure and areal distribution of the rocks. Plate IX, *B*, shows a view northward from a point on the divide between the two branches of the Rathlatulik about 3 miles east of camp C 11. The white areas in the view are limestones and the darker parts are schist. Some of the schists are undoubtedly derived from rocks of igneous origin, but others were unquestionably deposited as sediments. Most of the limestones are ordinary calcareous rocks, but some are dolomitic. In the view above referred to at several places in the eastern or right-hand belt of white rocks light-colored dolomites have been found. This fact points strongly to the conclusion that these beds represent the dolomitic portion of the Paleozoic rocks of the Kwiniuk region.

With these limestones black graphitic quartzites have been found here and there similar to those on Mount Kwiniuk. This type of rock is not so abundant as at the other places. Its apparently small extent is believed to be due in part to the greater amount of deformation and contact metamorphism whereby it has been transformed into a biotite schist or into a nearly white quartzite.

BLUFF-TOPKOK HEAD AREA.

The westernmost mapped area of rocks correlated with the Paleozoic rocks of the Kwiniuk region occur near Bluff and appear at several points along the western border of the area. Unfortunately, this part of the field has not been thoroughly surveyed, and considerable areas which, if more fully known, might belong to this series have been placed in the undifferentiated metamorphic rocks.

The Bluff region was not visited in 1909 and the account here given is taken from a summary report by Brooks[a] in 1906.

> Richardson, who through his acquaintance with adjacent areas had a broader knowledge of the Bluff region than the writer, divided the bedrock terranes into three groups—(1) a massive gray crystalline limestone, (2) a mica schist with some interbedded graphitic limestone, and (3) a formation of massive limestones and mica schist. The writer's observations hardly bear out the correctness of this succession of beds, for it appears to him that there is only one massive white limestone which is succeeded by a mica schist and graphitic limestone formation. Some facts are presented below which would indicate that the mica schists are, in part at least, altered intrusives and hence do not mark any definite stratigraphic position.
>
> The larger structures of the Bluff region appear to be simple, but there are many minor complications. The heavy limestone has been uplifted into a low dome, whose longer axis stretches approximately N. 70° E. About 3 miles northeast of Bluff this structure carries a limestone underneath the younger mica schists.

It is evident from this description that lithologically the same rocks are represented here as in the Kwiniuk region, namely, limestones, some of which are dark-colored, suggesting the Devonian-Carboniferous limestone and black graphitic slates. The fact that these rocks are cut by intrusives of greenstone is also indicative of a similarity between the two regions. Although Brooks correlated these rocks with the Port Clarence limestone, the fact that Devonian-Carboniferous rocks, as well as Silurian and possibly older ones, may be represented makes it undesirable to continue that correlation, and these rocks are therefore mapped as Paleozoic.

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[a] Collier and others, The gold placers of parts of Seward Peninsula, Alaska: Bull. U. S. Geol. Survey No. 328, 1908—The Bluff region, pp. 285–286.

AREA AT THE HEAD OF THE MUKLUKTULIK.

The fifth and last large area represented on the southeastern Seward Peninsula map as belonging to the Paleozoic rocks is the eastern area in the Mukluktulik divide. This belt trends north and south. On the south it forms Bald Head or Isaacs Point where it is cut off by the sea. To the north a prominent hill locally called Haystack Mountain, on the north side of the Koyuk Valley, marks the farthest extent in that direction; beyond that point more recent igneous rocks have cut or covered the formation.

At the eastern margin of the area is a belt of white quartzite a mile or so in width. This is cut off by basic lavas that form the hills east of Alameda Creek. It is believed that the quartzite is equivalent to the black quartzitic and graphitic slates of Mount Kwiniuk, so metamorphosed locally by the igneous rocks that the carbon has been destroyed. West of the quartzite ridge there is a considerable thickness of calcareous schist with some white limestone bands, but on the divide at the head of Coal Creek a white, completely recrystallized limestone forms knobs trending a little east of north. Sink holes 500 to 600 feet above the sea are common, and some of them show ledges of limestone. This limestone has a strong fetid odor when freshly broken, and shows no original bedding or signs of organic remains. Farther west, about 7 miles from camp B17, at the mouth of the Koyuk, alternations of black graphitic quartzitic slates or schists and limestone beds form an intricate complex about 2½ miles wide trending northeast. The dips, so far as observed, were all to the east, but the arrangement of the different lithologic units is such as to suggest extensive faulting or overturned and crumpled folds.

Northwest of this belt of alternations of black slates and limestones for 4 miles is a series of dark limestones and calcareous schists dipping southeast and striking northeast-southwest. Exposures in this field are rare and unsatisfactory. The western part of this area is formed of a belt 2 miles wide of black carbonaceous slates and schists. No outcrops in place were observed, but the unmixed character of the float points to the conclusion that this is the country rock. It is in all essentials lithologically identical with the slates in the belt farther east already described, and slight hesitation is felt in ascribing it to the same series. More detailed work would undoubtedly permit further differentiation of these two distinct lithologic phases. For the present it may be stated that whereas if, on the one hand, the dip is considered to be dominantly to the east the section shows a black slate and quartzite at the base, succeeded by a thick limestone and limestone-schist member, succeeded by an alternating series of limestones and black slates, succeeded by another thick series of limestones with some schistose phases, and this in turn followed by a massive quartzitic horizon. On the other hand, there are strong reasons for believing that reduplication through faulting and folding may occur, hence there may be only one limestone and one black slate member. No dolomite was observed in this section.

Mendenhall, who saw the section of these rocks near Bald Head, says:[a]

> Along the west side of Bald Head gray and white marbles occur infolded with thin-bedded limestones and schists, and blocks of these rocks cover the beach. The point of the promontory is a mass of heavy black graphitic beds, and the eastern face exhibits a slaty and schistose phase, the rocks being generally dark. Dip and strikes are variable and the relations are obscure, but evidently complex.

SUMMARY.

From the foregoing description it is evident that there is a group of limestones, dolomites, and quartzose graphitic schists which, from the few fossils found, is known to include Silurian and Devonian-Carboniferous horizons. These rocks are on the whole less metamorphosed than certain quartz-chlorite schists on which they are supposed to rest. In general, the trend of the formation is north-south, with complex folding and faulting. No signs of a conglomerate were noted in any part of the section, and it is presumed that the Paleozoic rocks were laid down at some distance from the shore line. This conclusion is further suggested by the wide distribution of lithologically identical rocks over the southeastern part of Seward Peninsula where the metamorphic rocks outcrop. Further investigation might lead to a more precise differentiation of the various lithologic units, but such subdivision would probably not add greatly to the understanding of the economic problems connected with this group of rocks.

CRETACEOUS SEDIMENTARY ROCKS.

In the eastern part of the Nulato-Council region a large area, extending from Norton Bay and Koyuk River on the west to beyond the Yukon on the east, is occupied by a series of sedimentary rocks, including conglomerates, grits, sandstones, shales, and thin lignite beds. These deposits extend north and south beyond the field investigated. The only other rocks within this area are a few dikes near Bonanza Creek, the intrusive massif of Christmas Mountain, and relatively small areas of Tertiary effusives on the Koyuk and near the mouth of the Koyukuk.

Beds similar to certain of those found in the main sedimentary area are exposed at the mouth of Koyuk River and on its north bank at a point about 4 miles west of the mouth of East Fork, also

[a] Mendenhall, W. C., A reconnaissance in the Norton Bay region, Alaska, in 1900, a special publication of the U. S. Geol. Survey, 1901, p. 202.

in the long ridge which forms the Kwik-Tubutulik divide. These outlying areas of sedimentary rocks comprise only a few square miles.

The unmetamorphosed, consolidated sedimentary rocks of the region apparently comprise a single conformable series of great thickness. Two distinct types of deposits are recognized and will be described in their order of occurrence as follows: First, a basal conglomerate called in this report the Ungalik conglomerate; second, an overlying group of sandstones and shales called the Shaktolik group. The Shaktolik group is separated into two divisions, the lower distinguished by a preponderance of sandstones over shale, and the upper in which shales are in excess.

UNGALIK CONGLOMERATE.

The lowest member of the Cretaceous sedimentary series, a basal conglomerate of marine origin, is called the Ungalik conglomerate, after the river of that name, along whose lower course it was first noted. This formation occurs along East Fork of the Koyuk River and on the Kwik-Tubutulik divide. (See Pl. V, in pocket.)

The Ungalik conglomerate is exposed in steep-faced cliffs along Ungalik River and forms most of the prominent range of hills between the river and the coastal plain from Bonanza Creek north to a point about a mile below camp A17. Here the strike changes and the conglomerate appears in the hills east of the river. Its eastern limit was not determined, but its characteristic pinnacled topography does not extend far beyond this point.

In this locality the conglomerate ranges in texture within moderate limits, the coarsest phases carrying bowlders up to 3 feet in diameter. Assortment and bedding are poor. The most characteristic materials are a variety of porphyritic rocks and abundant angular feldspar crystals in the sandy matrix. A strong red coloration on weathering indicates an abundance of iron. The bedding is so indefinite and obscure that no conclusive evidence as to the attitude or thickness of the formation could be obtained. However, a thickness of at least several hundred feet is certain.

That deformation has been intense is indicated by the abundant slickensides developed both in the conglomerate and at its contact with other members. On the Ungalik east of camp A16 it is faulted against black slates which represent a much higher horizon in the series. At this point the slates are approximately vertical. In the bluff on the Ungalik south of camp A16 are several dikes intruded in the conglomerate. They are much faulted and indicate the amount of deformation which has occured throughout the vicinity. The conglomerate area is characterized by a rather rugged topography. Where there is considerable relief the hilltops and sharp ridges are often marked by bare, rugged pinnacles.

The conglomerate is the basal formation of the sedimentary series. It is made up of rounded débris derived from the older formations, on which it rests unconformably. It chronicles a period of more or less gradual advancement of shore conditions.

On East Fork the conglomerate occupies a belt about 8 miles wide, trending north and south. It is similar to that in the Ungalik Valley in texture and in the lack of assortment and bedding. The materials include a variety of igneous rock types in the outcrops near camp B11. Farther west, near camp B12, it consists of a variety of granitic rocks of local derivation. No conclusive evidence as to the attitude or thickness of the conglomerate in the East Fork region was available, but the relief developed in the formation indicates a thickness of at least several hundred feet.

Along the Kwik-Tubutulik divide the Ungalik conglomerate belt has a width of from 3 to 5 miles. The main ridge forming this divide and its northward extension into the Koyuk drainage basin is composed almost entirely of limestone. The bowlders are smaller as a rule than those in the Ungalik and the East Fork localities. There is also greater variation in texture, the deposits including grits and limy sandstone layers. Some of the latter furnished fossil plants of Cretaceous age. Fossil corals taken from a limestone bowlder in the conglomerate on the Kwik-Tubutulik divide about 5 miles south of the camp C4 were of Paleozoic age.

Along the col at the head of Lost Creek the conglomerate is relatively free of limestone and schist material, being made up mainly of igneous rocks and quartz. Vertical dips were observed at a number of places and probably represent the general attitude of the beds in most of this area. The high dips and the fact that the conglomerate area is surrounded by Paleozoic rocks show that the younger beds have been folded or faulted downward from their former relative position, and indicate the extensive removal of Cretaceous sediments from areas which they formerly occupied. As in the other occurrences, the conglomerate marks a period of littoral erosion and deposition, and being derived from the rocks upon which it rests, its relation to them is that of unconformity.

Mendenhall notes[a] the occurrence of unaltered sediments at two points along Tubutlulik River. He says:

> Eleven or twelve miles above the mouth of the Tubutulik some bluish and shaly sandstones and fine quartz conglomerates, entirely unaltered, but dipping 50° or 60° NE., outcrops along the river bank. Two or three miles above this exposure is another of soft, brown sandstone and fine conglmerate with blue clay shales.

[a] Mendenhall, W. C., Reconnaissance in the Norton Bay region, Alaska, in 1900, a special publication of the U. S. Geol. Survey, 1901, p. 205.

A. SANDSTONES AND SHALES OF SHAKTOLIK GROUP, SHAKTOLIK RIVER.

B. CONCRETIONS IN SANDSTONES OF SHAKTOLIK GROUP.

Being immediately adjacent to the conglomerate area and having suffered similar deformation, these sediments probably belong with the conglomerate in the same general series.

About 70 miles east of Nulato, below the mouth of Melozitna River, a series of conglomerates, grits, and shales is exposed along the Yukon. According to Spurr[a] these beds overlie Paleozoic rocks and are made up of materials derived from them. Farther down the Yukon the conglomeratic beds are less important and the series consists mainly of grits, sandstones, and shales.

The determination of fossils collected by Atwood in 1907 from a number of horizons of this series refers them all to the Upper Cretaceous. The Melozitna locality may be regarded as having been at one time the eastern margin of the area of Mesozoic deposition, as the conglomerate areas near Norton Bay indicate the one time western margin.

An exact correlation of the conglomerates of Melozitna River and of the Norton Bay localities is not advocated, though by no means impossible. The similarity of deposits means that the same conditions which prevailed at one time at one of the localities prevailed at some time during the same general period at the others, littoral condition necessarily existing throughout the life of the Mesozoic Basin.

SHAKTOLIK GROUP.

The Shaktolik group, so called after the river of that name, which affords a good section of the beds, includes a thick series of sandstones, shales, and grits. This name is used to designate all the beds between the Ungalik conglomerate and the top of the sedimentary series. Beds of this group are widely distributed in the sedimentary area and occupy most of its space.

For convenience of description a separation into two divisions is made, the lower characterized by abundance of sandstones, the upper by the predominance of shales. Each will be treated separately in the order of stratigraphic position and localities.

LOWER DIVISION OF THE SHAKTOLIK GROUP.

Shaktolik River and westward.—Along Shaktolik River and westward the Shaktolik group is made up of alternating beds of sandstone and shale, the latter aggregating only a small part of the total thickness. (See Pl. X, *A*.) The sandstones are usually fine grained, dense, and compact, and in some places resemble fine-grained igneous rocks so closely in apearance and in constituent minerals that their

[a] Spurr, J. E., Geology of the Yukon gold district, Alaska: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1898, p. 189.

true character was determinable only with the aid of the microscope. Near camp A10 some of the beds exhibit a peculiar concretionary structure, large spherical masses breaking down in concentric shells under the blows of a light hammer. (See Pl. X, *B*.) Another unusual structure shows in the form of weathered surfaces seen at a number of places in the sandstone area, especially near camps A12 and B6. The surfaces mentioned were marked by linear striations and flutings and by lobate forms suggesting surface flow. (See Pl. XI, *A*.) Whether these structures are original or have been developed by postdepositional movements between beds is not known. Ordinary ripple marks are absent in the same localities.

Microscopically, the sandstones show a very even texture. The sand grains are seldom well rounded and are especially sharp in the finer-grained beds. In composition they include feldspars, quartz, calcite, pyroxenes, amphiboles, micas, and fragments of dense igneous rocks. Most of the material of the sandstones could be derived from the rock types that are found in the Ungalik conglomerate. Some of the lower sandstone beds resemble the matrix of the conglomerate closely, pointing to continued sedimentation from the same source. Other beds approach limestone in composition, the sand grains being mainly calcite derived from older limestones. Calcite deposited from solution is the principal cement. Locally, secondary minerals of a serpentinous character, due to the post-depositional alteration of femic minerals, forms the cement, giving the rock a speckled or mottled appearance. Such alteration, however, is not general, the sandstones being remarkable for the unaltered condition of the minerals they contain. The rocks are not highly colored as a rule, shades of gray being most common in fresh specimens. Many of the finer deposits are colored black by carbonaceous matter which they contain. Others have reddish and reddish-brown tones, due to iron oxides. Iron staining is common on weathered surfaces.

The beds have been extensively deformed, close folding along northeasterly and southwesterly axes having occurred. The dips are very high over most of the area, varying within a few degrees on either side of 90° along the Shaktolik. The stronger beds often find topographic expression in prominent ridges, but much of the topography has smooth rounded forms in which both lithology and structure are obscured.

Where good exposures were observed much faulting was noted. In other places, where the structure was obscure in detail, the relation of beds indicated extensive displacement. It is safe to assume that faulting on both a large and a small scale has been an important part of the deformation of the group. Schistosity has been developed locally in places near the structural axes, especially in the fine-grained carbonaceous members.

A. SURFACE MARKINGS ON SANDSTONES OF SHAKTOLIK GROUP, INGLUTALIK DIVIDE.

B. GRANITE PINNACLES NORTH OF KWINIUK RIVER.

The actual thickness of the Shaktolik group at any point is not known. A partial section exposed on the headwaters of the Inglutalik River gives an apparent thickness of tens of thousands of feet. Due allowance for the repetition of beds by faulting being made, the group is still of very great thickness.

The lower or sandy division of the Shaktolik group overlies the Ungalik conglomerate in apparent conformity, and probably grades upward without a break into the upper division of the group, which consists mainly of black shales, and though recognized as distinct in type, could not be differentiated from the lower beds in mapping without more detailed survey.

Near Nulato.—A group of sandstones, shales, and grits with minor lignitic beds outcrops along Yukon River near Nulato. These beds have been known as the Nulato sandstone since first visited by Dall in 1866. They are only a part of a great series of similar deposits which are included in the Shaktolik group. The work in this region has not been sufficiently detailed to determine whether it will be possible to retain the name Nulato for one of the formations of this group.

The early writers, Dall and Spurr,[a] considered these beds of Tertiary age, but subsequent visits of Collier (1902), Hollick (1903), and Atwood (1907) and the study of their collection by Stanton and Knowlton have shown them to be of Upper Cretaceous age. The investigation of 1909 indicates that not only are these beds of Cretaceous age, but that a thickness of several thousands of feet of beds of undoubtedly Cretaceous age overlies them.

In the Nulato section sandstones predominate over the shales, grits, and lignite beds that make up the rest of the group. Notes furnished by Atwood[b] show that different types of beds alternate in close succession. Fossil plants, lignite deposits, cross-bedding, and ripple marks indicate shallow water conditions during part of the period of deposition, but alternating with these are beds bearing marine shells and worm borings. Some of the sandstones are of the even-grained, dense type common in the Shaktolik region and also noted near camp A2. On the whole, the sedimentary rocks near Nulato show a greater variation in type and indicate more changeable conditions of deposition than the rocks of the localities farther west.

The structure near Nulato is rather simple, the beds dipping in general to the northwest at angles up to 40° or 50°. Locally the beds are much faulted and crushed along the axes of minor folds. No definite measurement of the section was attempted, but it must be many thousand feet in thickness. The relations of these beds to the

[a] Dall, W. H., Bull. U. S. Geol. Survey No. 84, 1892, pp. 247–248. Spurr, J. E., Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1898, p. 196.

[b] Unpublished information; report in preparation.

underlying formations are not evident at this locality. They occupy the area west of the Yukon to the locality of camp A5, where they are overlain, probably conformably, by the black shales which form the upper division of the Shaktolik group.

Bishop Rock.—Bishop Rock is a low, rocky knob on the Yukon about 10 miles above the mouth of the Koyukuk. It is composed of compact limy and shaly sandstones. Fossils collected here by Atwood in 1907 were determined as Upper Cretaceous.

Near Melozitna River.—Overlying the basal conglomerate correlated with the Ungalik conglomerate near the mouth of the Melozitna River and downstream for 30 miles or more a series of sandstones, grits, and shales outcrops along the Yukon. In lithology, fossils, and relation to the basal conglomerates these beds are similar to the Shaktolik group farther west and are regarded as belonging to that group.

UPPER DIVISION OF SHAKTOLIK GROUP.

The upper division of the Shaktolik group occupies the central part of the sedimentary area along the Nulato-Gisasa divide and westward to the head of Shaktolik River. It consists predominantly of black shales, but contains subordinate beds of calcareous sandstone. Some of the latter 5 miles west and 2 miles south of camp A5 furnish invertebrate fossils of Upper Cretaceous age.

This group of beds probably represents a vertical gradation into finer sediments upward in the series, though lateral gradation is not impossible. The shales are very carbonaceous, indurated, and on weathering in places break down into pencil-like fragments. Schistosity has been developed locally near structural axes in some of the more carbonaceous members. The more resistant members stand out in strong ridges; the slopes are steep, covered with fine talus, and almost barren of vegetation. Structurally the shales agree with the underlying standstones, with which they are conformable. Black shales accompany the sandstones throughout the Shaktolik group, but the part of the group in which they predominate strongly enough to be distinguished as a separate division probably does not include more than a few thousand feet.

IGNEOUS ROCKS.

From the foregoing description of the sedimentary rocks it is seen that the Cretaceous deposits give a good horizon to which to refer different geological activities. The pebbles in the conglomerate at the base of the Cretaceous show what rocks were in existence when the beds were deposited, and all igneous rocks cutting the Cretaceous must be later than the beds they cut. For this reason the igneous rocks of the region have been divided into pre-Cretaceous and post-Cretaceous. Each of these main subdivisions contains rocks of different mineralogic composition and field relations and was formed under different conditions; both show intrusive and effusive rocks and afford much material for detailed petrographic studies, which, however, have not been attempted in the preparation of this report.

The larger areas of pre-Cretaceous igneous rocks are the flanks of the Kaiyuh Hills, the Buckland-Kiwalik divide, the Bendeleben and Darby ranges, the region around Bluff, and numerous small areas in the metamorphic complex. The larger areas of post-Cretaceous igneous rocks in the Yukon Valley are at the mouth of the Koyukuk and south of Kaltag; in Seward Peninsula they are in the Koyuk River Basin, especially in the central portion, extending to the head of Kiwalik River; at the very head of the Koyuk, extending to Noxapaga River; and at the lower part of East Fork, extending into the Buckland River basin.

PRE-CRETACEOUS IGNEOUS ROCKS.

In the long time represented by the pre-Cretaceous history of the region there are two distinctly marked periods of much geological significance. One of these preceded the dynamic metamorphism of the region and the other followed it. Rocks formed in the earlier period show structures due to this deformation, whereas those formed afterwards have not been much metamorphosed. A division of the pre-Cretaceous igneous rocks into two groups, metamorphic and nonmetamorphic, may be made, and this grouping will be followed in this report.

METAMORPHIC IGNEOUS ROCKS.

Rocks of igneous origin earlier than the period of metamorphism have been recognized in many parts of the region. The four larger areas mapped are in the Kaiyuh Hills, east of the Darby Range, in the belt extending northward from Bluff in the western part of the area, and north of Omilak Creek. All of these areas have features more or less in common, but it is by no means certain that all of them have been formed at the same time or are mineralogically identical. Furthermore, there is but little doubt that other metamorphic igneous rocks might be recognized if investigations had been carried on in greater detail, and doubtless some of the area mapped as undifferentiated metamorphic rocks is formed of igneous rocks.

Reference has already been made on page 40 to the belts of metamorphic igneous rocks occurring on both flanks of the Kaiyuh Hills. These were described by Maddren as consisting of diabasic rocks of probably effusive character. They are less metamorphosed than the older sedimentary rocks which form the Kaiyuh Hills on which these ancient lavas probably lie unconformably.

In Seward Peninsula the metamorphic igneous rocks are usually greenish in color, and differ much in degree of foliation; in the central part of the peninsula they are high in soda and low in quartz. Usually, where schistose, the rocks have had secondary albite developed and become greenish feldspathic schists. Although the feldspathic character may be produced in other ways, as, for instance, by the contact effect of igneous rocks, it is believed that in a large way the presence in this field of highly feldspathic schists is strongly suggestive of the igneous origin of the rocks in question, and this is assumed to be true if contradictory evidence was not observed.

The clearest evidence concerning the greenstones and associated feldspathic schists is afforded by the cliff exposures along the east coast of the Darby Peninsula. Along this part of the coast are numerous dikes and sills of basic composition cutting the Paleozoic rocks. A particularly clear example of a greenstone intrusion of this sort is shown in Plate VIII, *A* (p. 46). At this place, which is between

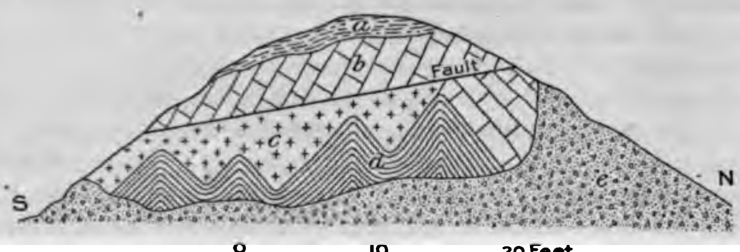


FIGURE 4.—Relation of greenstone, limestone, and slates, east coast Darby Peninsula. *a*, Soil and waste; *b*, limestone; *c*, greenstone; *d*, black slates; *e*, talus.

the Kuiuktulik and Walla Walla, light and dark banded Paleozoic limestones have an unusually low dip. These have been intersected by nearly vertical cleavage, and parallel to this cleavage the greenstones have been intruded. The large white masses shown in the picture are calcite veins of later formation, probably contemporaneous with the succeeding period of mountain building.

The structural relations of the greenstones are in places complex and show that these rocks have been subjected to considerable disturbance. Figure 4 illustrates an exposure of slates, limestones, and greenstones on the eastern coast of the Darby Peninsula about midway between the mouth of the Miniatulik and the Kuiuktulik. The greenstone intruded slates and limestones and has subsequently been folded into a number of appressed folds. Thrust faulting then took place along the plane indicated so that the south-dipping limestone was superposed on the greenstone and the slates giving a section as indicated in the figure. The axis of folding at this place is about N. 70° E. and the folds pitch toward the west.

In many places the deformation and accompanying metamorphism of the greenstones has gone so far that the original characters of the rocks are obliterated and it is not certain what origin is to be assigned. Brooks, in a study of the Bluff region, found schistose rocks which seemed to show by their areal relations igneous rather than sedimentary characters. Concerning these schists he says:[a]

Mica schists occur as irregular masses within the limestone belts and although they do not differ lithologically in any very essential way from the schists believed to be of sedimentary origin, their mode of occurrence strongly suggests that they are altered intrusions. The most striking example of this is seen in the cliff exposures just east of the mouth of Daniels Creek (fig. 5). Here an irregular mass of mica schist is inclosed in limestone walls. Lines of faulting have obscured the original relations of the two rocks, but the outline of the schist mass is very suggestive of an intrusion. Further evidence of the intrusive character of some of these schists is found in the fact that at various localities the limestone walls near the contact with the schists are more or less metamorphosed. These facts, together with the irregular distribution of the schists, indicate an igneous origin, though it must be confessed that the evidence is by no means conclusive.

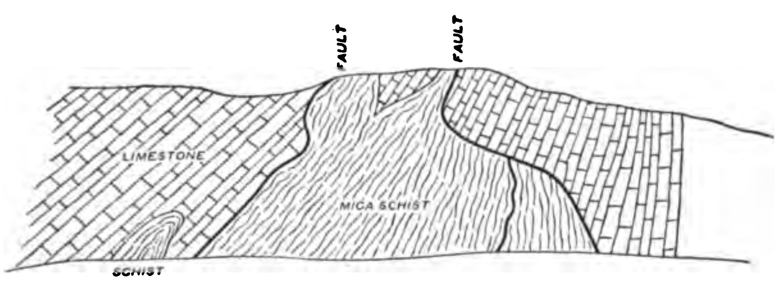


FIGURE 5.—Cliff exposures near mouth of Daniels Creek, Bluff region.

At several places the actual gradation from an unquestionably igneous rock into a green feldspathic schist has been observed. Here and there in the hills south of camp C15 are examples of this sort, and although it is not intended to assert that all the feldspathic schists are of this origin, it is certain that many if not most of them are formed in this way.

An exposure of metamorphosed igneous rock is afforded near the Omilak mine. Figure 6 shows the general geology in the neighborhood of the mine, with the intrusive cutting across the western limb of the limestone. Plate IX, *A* (p. 50), supplements this map by showing the general appearance of the same hill from the south. In this view the dark area in the center of the view is the igneous rock, and an apophysis is represented by the dark band which cuts across the right-hand limestone area. From a study of this rock under the

[a] Collier and others, The gold placers of parts of Seward Peninsula, Alaska: Bull. U. S. Geol. Survey No. 328, 1908—The Bluff Region, pp. 285–286.

microscope it has been determined that it consists of olivine, a light-colored amphibole probably tremolite, very abundant light-green garnet and muscovite, with some accessory ilmentite and apatite and secondary serpentine. This is an unusual phase of the greenstone series and has not been recognized elsewhere.

NONMETAMORPHIC IGNEOUS ROCKS.

There are three large areas of pre-Cretaceous nonmetamorphic igneous rocks to which attention should be called. These are the Darby Range, the Kiwalik-Buckland divide, and the Bendeleben Mountains. In addition, several smaller areas, such as Kiwalik Mountain, are found in the region, but as they show the same features

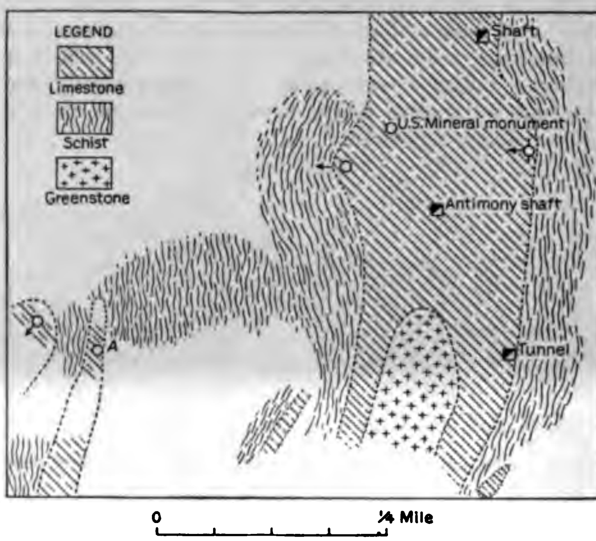


FIGURE 6.—Sketch map of the vicinity of the Omilak mine.

as the igneous rocks in the larger areas they will not be described separately.

Mendenhall, who studied portions of the Darby Range in some detail, says:[a]

Cape Darby and a broad belt of country extending 55 miles northward from it with a maximum width of about 12 miles is occupied by a great intrusive body of granite and granitized rock which exhibits considerable variation in texture and mineralogical composition, but is regarded as belonging to one geological body.

A few miles below Cheenik, along the eastern shore of Golofnin Bay, the rock is diorite porphyry with large tabular phenocrysts of andesine or andesine-oligoclase, some colorless pyroxene, and abundant hornblende in part at least secondary. Quartz is present but often in very inconsiderable amounts, and

[a] Mendenhall, W. C., op. cit., p. 204.

titanite is an inconspicuous accessory. This phase or a slightly more acid one is rather largely represented in this portion of the mass extending at least 5 to 6 miles east from its western border.

Near the eastern edge of the northern part of the area in the Tubutulik Valley the rock appears as a coarsely crystalline aggregate of pale brownish orthoclase and smoky quartz with a little biotite. A gneissoid phase of the same rock occurs along the western side of its western limit.

Distinct contact phenomena in the schists and slates while sometimes present are not so abundant as one would expect. The inference is that the intrusion was slow and deep-seated and affected the intruded rock generally, rather than locally. This inference finds support in the coarse texture and porphyritic character of the diorite even at its borders.

In 1909 it was the intention of the party to avoid revisiting the areas already studied by Mendenhall, so that in but few instances does the work overlap. From this later study it was found that the areal distribution as already given by Mendenhall required but slight modification, but that the number of different kinds of rock was more complex than his report indicated. There are at least two distinct types of granite, one with marked porphyritic development and the other of even grain.

The largest area of the porphyritic granite is in the Kwiniuk basin extending from a little east of camp C14 to at least 4 miles north of camp C15. In addition, the same rock was found on the seacoast at the mouth of Carson Creek and is probably the same as the granite with brownish feldspar described in the northern end of the belt. This rock is characterized by a coarse-grained mass of quartz, orthoclase, and a little biotite, the various grains averaging about 0.2 inch in diameter, with large orthoclase crystals averaging about 1½ inches in length scattered abundantly through the rock. A few inclusions of diorite were found in the porphyritic granite, one of which showed calcite-filled cavities, probably amygdaloidal in origin. Typically the porphyritic granite weathers into fantastic knobs and pinnacles similar to those shown in Plate XI, *B* (p. 58). This feature is also shown more extensively developed in Plate III, *A* (p. 30), the pinnacles shown being probably of granite of this type.

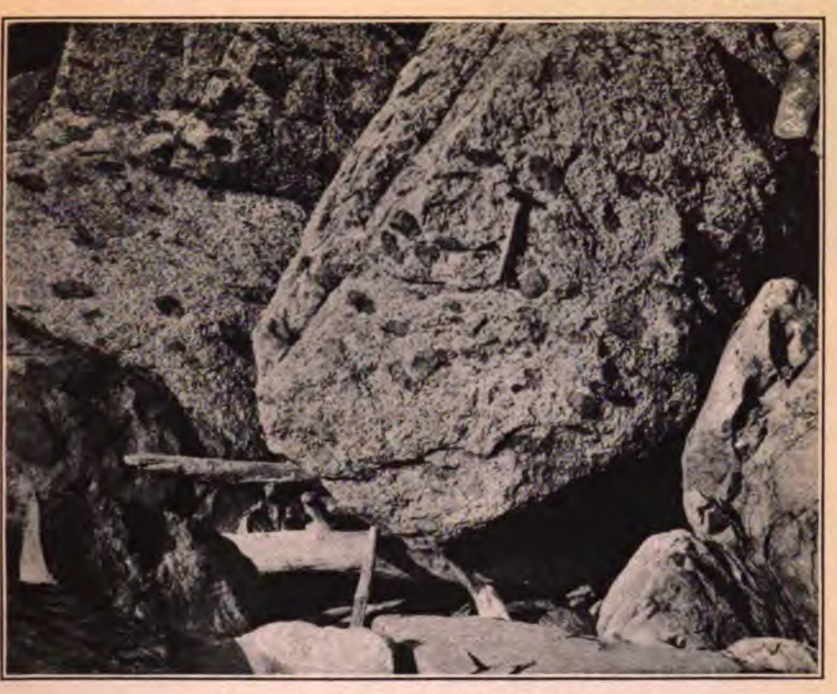
The even-grained granite may be of the same age as the porphyritic granite. If this is the case the two may have consolidated under different conditions. It does not seem evident from the field relations, however, that the porphyritic rock cooled under essentially different conditions except that the porphyritic granite forms larger masses than the finer-grained type. Mineralogically the even-textured granite consists of quartz, both orthoclase and plagioclase feldspar and biotite. Dark-colored silicates, although present, form but a relatively small amount of the rock. It occurs usually in rather narrow dikes, and no large area of this type is known in the Darby Range. Dikes of this granite have already been noted in previous pages as cutting the Paleozoic rocks at many places. Plate VIII, *B* (p. 46), shows a nearly vertical granite dike, the light-colored rock (on which the hammer rests) cutting across the structure of the metamorphic limestone and sending apophyses into it.

Diorite also occupies large areas in the Darby Range. In composition it ranges from a normal amphibole plagioclase rock to one containing quartz and orthoclase in addition to the usual constituents. The plagioclase is apparently andesine-oligoclase; that is, about midway in the soda-lime series. Accessory apatite, titanite, muscovite, and metallic minerals in small amounts were noted in several examples of this rock studied microscopically.

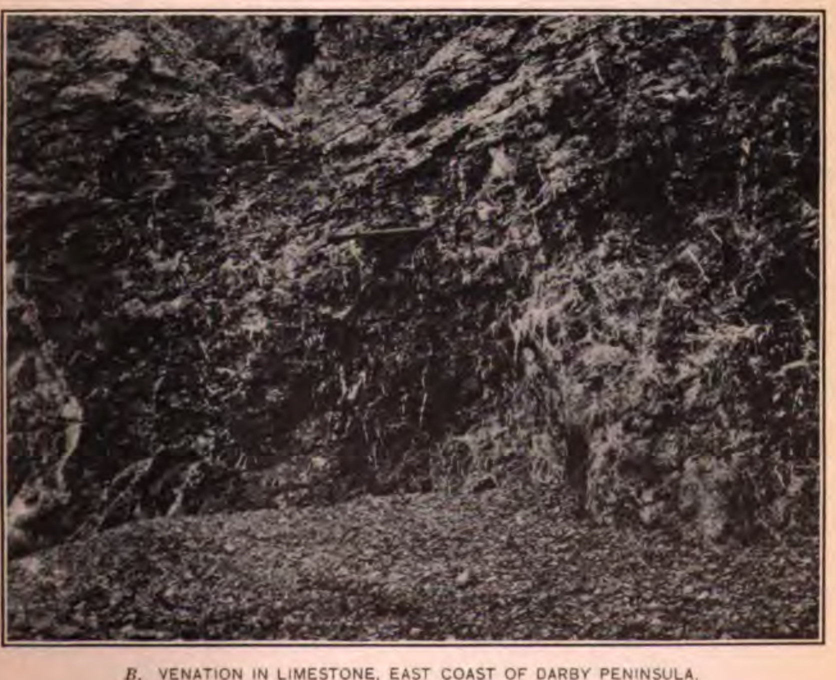
From the fact that inclusions of diorite are found in the porphyritic granite, it is assumed that the latter is younger than some of the diorite. Plate XII, *A*, however, shows that there is more than one diorite represented in the region. In this view the large light-colored area on which the hammer rests is porphyritic granite with numerous inclusions of diorite. Unfortunately in this picture the further fact that the porphyritic granite itself is an inclusion in the dark igneous rock which forms the lower left-hand portion of the view is not shown, although this fact is clearly proved by the exposure in the field. It should further be noted that in this later diorite intrusion are inclusions of the older diorite. Although the similar color makes the two diorites difficult to distinguish in this view, several of the older diorite inclusions may be recognized at the extreme left below the porphyritic granite-diorite contact.

In addition to the granites and diorites there are several other types of rocks, the distribution and relations of which are not sufficiently clear to allow their differentiation. One of these rocks is a quartz porphyry with double terminated quartz crystals and plagioclase as phenocrysts in a ground mass of quartz and orthoclase in a micropegmatitic intergrowth. Accessory green hornblende, apatite, and magnetite with secondary kaolin, muscovite and chlorite were also present. This type of rock was found particularly in the hills south of camp C13 in the divide between the Kwiniuk and the Etchepuk.

Another unusual type of rock forms a large area in the Kwiniuk divide south of camp C13, extending westward an undetermined distance and southward to beyond camp C14. It is dark colored, with lath-shaped phenocrysts an inch or more in length of orthoclase feldspar. The groundmass is composed of orthoclase, albite, oligoclase, green hornblende, ægirine augite, and biotite, with accessory titanite in great abundance, and some apatite. Usually the pyroxene forms cores around which amphibole has been developed, probably by the alteration of the pyroxene. The absence of quartz and the high soda content distinguish this rock from the others already described.



A. INCLUSIONS, EAST COAST OF DARBY PENINSULA.



B. VENATION IN LIMESTONE, EAST COAST OF DARBY PENINSULA.

Another unusual type of igneous rocks was found on the hill about three-fourths of a mile north of camp C22 on a branch of Kachauik Creek. It is rather closely associated with rocks of the fine-grained granite type, but the precise relations are not known. It is a light-colored fine-grained rock with a few scattered phenocrysts of nepheline and sanidine. In the ground mass, which is very fine-grained, are albite, nepheline, sanidine, ægirine augite, fluorite, eudialyte, riebekite, and biotite. The high soda content suggests correlation with the other soda-rich rock previously described. which was also wanting in quartz.

Rocks similar to the Darby range intrusives, with the exception of the last three phases, have been found in the pebbles of the Cretaceous conglomerate, and no hesitation is felt in ascribing them to an age prior to the Cretaceous. It is also evident from the studies in the field that all of these rocks cut the Paleozoic series and have not been dynamically metamorphosed to any marked extent. That there have been several periods of intrusive activity is shown by the relations of the diorites and porphyritic granites described on page 66. Whether, however, these periods were separated by any considerable time interval or whether they really mark only one major period of intrusive activity has not been determined.

Few new facts of importance have been added to those already published by Moffit concerning the igneous rocks of the Kiwalik-Buckland divide. According to this geologist[a]—

Much the larger part of the undissected mass which forms the divide between the drainages of the Kiwalik and the Buckland Rivers, and contains the highest elevations of the northeastern part of the peninsula, is made up of light-colored granular rocks and andesites associated especially toward the outer portions of the area with basalts and diabases.

In crossing the main part of the mass from the westward after leaving the highly metamorphic rocks of the Kiwalik Valley one meets first with basic rocks of the basaltic and diabasic type, followed by andesites which are well developed and form a large part of the ridge; finally, in the central portion of the complex, and forming a core for the whole, are discontinuous areas of more siliceous rocks, including a number of different varieties of granites, monzonites, and quartz diorites. Hornblende is the prevailing dark mineral of the granites. but at times biotite takes its place. By a decrease in the amount of quartz the granites approach syenites in composition, such phases being characterized by the abundance and larger size of orthoclase crystals, which usually show Carlsbad twinning and have a rough parallel arrangement with the small intervening spaces filled with hornblende, biotite, and a small amount of quartz. Titanite is abundant.

An unusual and highly interesting type was observed in the most southerly area of the granular rocks. The hand specimens show a dark-gray rock, composed of abundant large tabular feldspar crystals with a small amount of dark-

[a] Moffit, F. H., The Fairhaven gold placers, Seward Peninsula, Alaska: Bull. U. S. Geol. Survey No. 247, 1905, pp. 27–31.

greenish fine-grained filling. In thin section the rock is seen to consist of large crystals of orthoclase feldspar with a microscopic intergrowth of parallel plagioclase plates embedded in a groundmass of ægirine-augite, melanite, and small scattered plagioclase. The three last-named minerals fill spaces between the large orthoclase crystals, which are very subordinate in volume to the spaces occupied by the crystals themselves. Titanite and apatite are present, and a cloudy zeolitic decomposition product appears at times. The rock corresponds very closely in appearance and composition with the garnet-pyroxene malignites, which Lawson has described, from Maligne River in Ontario.

The diorites present no unusual features. They are nearly always of a light-gray color and are sometimes porphyritic. The prevailing feldspar is plagioclase with zonal structure. Some quartz is always present and the dark mineral is usually hornblende, but at times biotite. In one or two instances a well-developed flow structure was seen in large blocks of the diorite which were cut by small granitic or aplitic dikes largely feldspar.

Monzonites intermediate in composition between granites and quartz diorites are frequent. Orthoclase and plagioclase predominate while hornblende, biotite, and quartz are present; also titanite, magnetite, apatite, and occasionally zircon. All the granular rocks of this region are abundantly supplied with titanite which may often be easily seen in the hand specimen and is very noticeable under the microscope.

Andesites are abundant in the Kiwalik-Buckland divide and are probably the surface representative of an igneous magma corresponding in composition to the deep-seated diorites and monzonites. As already stated, they occupy, where observed by the writer, a position intermediate between the basic rocks of the western side of the ridge and the central acid ones and form a large part of the watershed. They are of a dark-gray or greenish color and on an exposed surface have a spotted appearance due to the alteration of the feldspar phenocrysts. Both hornblende and pyroxene varieties were seen, the latter containing considerable olivine in addition to pyroxene and showing the secondary mineral iddingsite. Alteration of pyroxene to hornblende was also observed. The feldspar is a basic variety, labradorite or sometimes anorthite, giving as alteration products chlorite and epidote.

Andesite breccias were found at various localities.

Little can be added from the work of 1909 to these descriptions and, although it has been possible in a measure to extend the mapping of these rocks, the additional data are so clearly evident on the map that further description is not required, except to note that the extension south of the Koyuk is formed mainly of rocks of the effusive rather than of the intrusive type. It should also be pointed out that whereas the intrusive rocks, which form the core of the Kiwalik-Buckland divide, are in all respects similar to the igneous rocks in the Darby Range, the effusive rocks which occur along the flanks have no recognized representative in the latter mountains.

The igneous rocks of the Bendeleben Mountains so far studied belong mainly to the group of granites, and, although here and there these rocks show gneissic phases, it is believed that, as a group, they are essentially contemporaneous and are later than the post-Paleozoic deformation. Lithologically the granites are indistinguishable from the granites of the Darby or Buckland-Kiwalik ranges, and it is assumed that such close similarity could not have occurred unless all these rocks had been derived from essentially the same magma at nearly the same time. It is on the basis of this assumption that the pre-Cretaceous age of the granite masses in the Bendeleben Mountains is postulated.

In the Bendeleben Mountains the geologic mapping is extremely conventionalized and the reader should regard this part of the map as suggesting the kind of geology probably to be expected rather than as a faithful portrayal of the actual areal distribution of the different types of rock. As mapped, however, this area serves to bring out the fact that there are numerous large bodies of igneous rock, in places many miles in diameter, and also that there is a most complex network of small dikes and sills, many of which are from a few inches to a few feet wide. The lithology and mineralogy of the two types, however, do not materially differ. Some of the small sills and dikes have as coarse texture as the more central parts of the larger masses. Both modes of occurrence are typically quartz-feldspar granites with some dark silicates and various accessory minerals. Even in the gneissic phases, Collier[a] states the structure must either be original or else the whole rock has recrystallized, for the microscopic examination shows little, if any, evidence of distortion or dynamic movement. In other places it is evident that the apparent gneissic structure is due to the replacement of adjacent schists, some of which are so thoroughly saturated by the igneous rock that much of the original character has been destroyed.

The contacts between the granites and the schists, however, are not always vague and ill defined, but in places are sharp and clear-cut. These differences are probably to be explained by the variations in composition of the wall rocks and also by the different depths of burial of the schists when the intrusions took place.

Associated with the normal granites are a few rocks of pegmatitic and aplitic phases which seem to have marked the later or closing stages of the intrusive period. In the pegmatities tourmaline is in places an important accessory mineral. One such pegmatite in particular was noted on Birch Creek near the pass to the head of Niukluk River. Mica in plates sometimes 6 inches or more in diameter is found in the pegmatites. A locality where particularly large mica plates have been reported is near Oregon Creek, a tributary of Fish River heading on the south slopes of the Bendeleben Mountains, and some attempts have been made to develop a commercial deposit.

At a few places dark basic dikes have been reported cutting the granites. Whether these belong to the pre-Cretaceous igneous rocks

[a] Collier, A. J., and others, The gold placers of parts of Seward Peninsula, Alaska: Bull. U. S. Geol. Survey No. 328, 1908, p. 104.

similar to the latest dioritic intrusion noted in the Darby range or whether they are post-Cretaceous is not known. They form relatively narrow dikes and occupy such small areas in the Bendeleben Mountains and so little is known about them that they will not be treated further in this report.

POST-CRETACEOUS IGNEOUS ROCKS.

Later than the deposition of Cretaceous sediments, intrusive and extrusive igneous rocks have been formed. As has already been noted, the main areas of the latter are in the Yukon and Koyuk basins and the only area of the intrusive rocks studied is in the lower part of the Ungalik Valley.

INTRUSIVE ROCKS.

Christmas Mountain, east of the lower part of Ungalik River, is the only center of post-Cretaceous intrusion noted. This prominent landmark is formed of an igneous complex, the relations of the various members being uncertain. The series of rocks grade according to texture from augite andesite to augite diorite. The main mass of the mountain is of the more granular type, in the coarsest phases having crystals up to 3 millimeters in diameter. This coarse phase contains abundant plagioclase, which has been determined to be albite, andesine, and labradorite. Augite, biotite, and olivine are also present as important constituents. Among the accessory minerals are magnetite and apatite, the latter being notably pleochroic. Secondary biotite, chlorite, sericite, and serpentine have also been recognized in this section.

Associated with the diorites in the western part of the area, probably in the form of a dike, is a porphyritic rock composed of orthoclase, plagioclase, biotite, and augite as the essential constituents, and with pyrite and calcite as accessory or secondary minerals. The phenocrysts in this rock are mainly feldspar, but a few are of light-green pyroxene.

The clearest evidence concerning the age of these rocks is afforded by exposures along the Ungalik, near camp A16, where dikes of essentially similar composition are found cutting the Ungalik conglomerate. Subsequent faulting has dislocated the dikes, but the amount of displacement indicated is not more than a few yards. Thin sections of specimens from these dikes show a light-colored porphyritic rock with phenocrysts of oligoclase and a monoclinic amphibole. In the main the ground mass has a trachytic texture and is composed largely of oligoclase and albite, with accessory apatite. Calcite, quartz, magnetite, kaolin, muscovite, and limonite, all probably secondary, were recognized. The limonite is in more or less rectangular patches, which points to its having been derived from the alteration of ferromagnesian minerals originally in this rock. At Bonanza Creek an intrusion of similar character cutting the black slates was found.

On the Shaktolik, at camp A12, a fine-grained quartz porphyry was recognized in the float, but the fragments were well rounded, as though they had been carried far, and there is no clue as to where the rock outcrops. The presence of this float, however, strongly points to the conclusion that it is from an intrusive later than the Cretaceous sediments. It is probable that a more extensive exploration of this region would show intrusive centers like that of Christmas Mountain in other parts of the Nulato-Norton Bay region.

EFFUSIVE ROCKS.

Effusive rocks of late geologic age are found at many places. All of these flows are probably not contemporaneous, but when they are considered in a broad way it is believed that they mark essentially one period of volcanism. Thus, though many years may have elapsed between successive flows, even in the same district, there seems to be strong reason for correlating them together as one group and regarding them all in a geologic sense as synchronous. Although the rocks described in this section are essentially lavas or surface flows, there are, of course, here and there dikes by which these rocks were brought to the surface. All of these rocks are characteristically olivine basalts with a vesicular structure.

The eastern locality of the post-Cretaceous effusives, the one near the mouth of the Koyukuk, was first carefully described by Spurr,[a] from whose account the following quotation is taken:

> Megascopically (the rock) is dark green and amygdaloidal, the amygdules being partly quartz and calcite. Under the microscope a large vesicle whose walls are lined with serpentine is filled with barite in interlocking plates. Many small ovoidal vesicles are lined with serpentine and filled with chlorite. These are comparatively large phenocrysts which are now pseudomorphed by calcite and serpentine, but were probably originally olivine. The structure of the groundmass is as if originally composed of holocrystalline plagioclase and augite. The augite is abundant and not greatly decomposed but the plagioclase crystals have been replaced by pseudomorphs of some other mineral in part, at least, isotropic. The rock is evidently a true olivine basalt considerably altered and decomposed.

Although the lavas represented in the Yukon Valley to the south of this place have not been described in detail they probably belong to the same period of volcanic activity. Similar lavas have been reported by Collier along the river south of Kaltag, but their extent has not been determined and there are no published descriptions of

[a] Spurr, J. E., Geology of the Yukon gold district, Alaska: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1898, pp. 245–246.

the occurrences. It seems probable, however, from the wide-spread distribution throughout the lower part of the Yukon basin of rocks of this same lithologic character that they must have formed extensive sheets.

Along the eastern border of Norton Bay volcanic rocks of a relatively recent age have been reported at many places. Within the region covered by this report two areas of vesicular lavas have been orally reported to the writers by Mr. J. T. Watkins, of the Coast and Geodetic Survey. These two areas are the Reindeer Hills and Besboro Island. No collections were made, but the description of the rocks clearly points to the conclusion that they are both to be included within this group. They probably mark a connecting link between the well-known volcanic flows of St. Michael on the south and of the Koyuk Valley on the north.

Concerning the lavas along the Koyuk, Mendenhall says:[a]

> The lava is a green, gray, or black rock, the color depending in part upon its freshness. It is compact or vesicular and usually porphyritic, olivine being the most conspicuous of the phenocrysts, although plagioclase is recognizable megascopically in some instances. Sometimes the vesicles are filled with opal; more frequently they are without filling. The rock varies in texture, having sometimes a very glassy groundmass and in other cases showing a coarse, well-defined, interstitial arrangement with almost no glass. * * * The basalt beds have not been disturbed since they were poured out. They are horizontal wherever their attitude is determinable and overlie all the other rocks. * * *

Moffit, who studied portions of the large lava sheet occupying the northwestern corner of the mapped area, as well as numerous other flows in contiguous areas to the north, writes as follows concerning these basalts:[b]

> In color the lavas are dark gray, green, or nearly black. They are usually very cellular or even spongy in appearance, but at times compact and without the amygdaloidal cavities. Outcrops of the older lavas in place are not plentiful, and the edges of the sheets where cut through by streams are marked by tumbled heaps of blocks resulting from the jointed columnar structure of the lava. In a few places they form flat-topped hills or mesas from 20 to 50 feet high, very conspicuous when viewed from a distance, and evidently the remains of partly eroded sheets. Agglomerate breccias were observed at several points. A study of the numerous specimens collected shows them to be made up of diabase and basalts, both rich in olivine. In the basalts, especially, olivine phenocrysts are abundant and very noticeable even in the hand specimens. Iddingsite is not infrequent as an alteration product of the olivine.
>
> That a succession of outbreaks of lava has taken place is shown in a number of places, but probably most plainly in the region about the head of Kuzitrin River, where positive evidence is afforded in the terraced condition of the different flows, three distinct benches occurring in one locality.

[a] Mendenhall, W. C., op. cit., p. 206.

[b] Moffit, F. H., The Fairhaven gold placers, Seward Peninsula, Alaska: Bull. U. S. Geol. Survey No. 247, 1905, pp. 31, 32–33.

Observations made by Collier on Noxapaga River showed these more recent lavas overlying gravels which are cemented near the contact by indurated clays and contain pebbles of an older flow—conclusive evidence that considerable time must have elapsed between the first outbreak and the solidification of the flows just described. The source from which the recent basalts of Noxapaga and Kuzitrin rivers were discharged lies to the southwest of Lake Imuruk, this being shown by the scattered lava cones as well as by the direction of movement of the flows themselves.

On the upper part of Koyuk River a similar relation of basalts and gravels was observed by Mendenhall. He found on the truncated edges of the schist 5 feet of gravel made up of schist, vein quartz, and granite; this in turn was covered by an undisturbed horizontal sheet of olivine basalt, which has been but little affected by the erosive action of the stream since it came to rest and was, therefore, believed by him to be of Pleistocene age.

During the field season of 1909 little detailed study of the lavas was made, and although the areal distribution of this group of rocks has been extended in certain places the additions are mainly concerning details rather than essentials. It seems evident that in the main they occupy the lowlands of the period in which they were formed, so that a thorough understanding of the distribution of the lavas would indicate the former topography. It is probable that more extensive investigations might show that these basalts occupy a greater area than is shown on the maps. For instance, the lava area at the head of the Mukluktulik probably connected at one time with the lava areas represented to the north of the Koyuk west of Peace River, and if the exposures were better in the gently sloping spurs west of Kenwood Creek it is highly probable that remnants of this sheet might still be found overlying the undifferentiated schists and the Paleozoic rocks. This patch of lava is probably older than those very late effusives that overlie gravel deposits of recent date, but, as before stated, it is believed that they both belong to the same general geologic group and were poured out on the deformed and eroded surface of the Cretaceous and older rocks.

Another small area of recent effusive rocks was reported by Mendenhall in the hills near Grouse Creek, a tributary of the Tubutulik. It covers the contact of the granites and Paleozoic sediments. This fact strongly suggests that the contact, being a zone of weakness, had been topographically a lowland, in consequence of which the lava flowed into the depression and being thickest there had remained, whereas the thinner parts had been entirely eroded away. There is no direct evidence as to the direction from which this lava came, but as no near-by areas of similar rocks are known except to the north it is assumed that this is the direction from which they flowed, although it is realized that this is little more than a working hypothesis.

On Bear River west of Council a small area of recent lava has been reported and specimens of the rock have been examined. It is a vesicular basalt similar in lithologic character to those from the Koyuk. There is probably only a small amount of the rock present, but little is known of the manner of occurrence or the areal relations.

VEINS.

Veins of different mineralogical character formed at different times and under different conditions have been noted at many places. They are abundant in the areas of metamorphic rocks, but are practically absent in the greater part of the area occupied by the Cretaceous sediments. Based on mineralogical composition there are two main types of vein filling; in one quartz predominates, in the other calcite. The former are of widespread distribution and are found in all the various kinds of rocks; the latter class, however, is almost entirely limited to the immediate vicinity of the limestone areas.

The veins in which calcite is the main filling are seldom extensive either horizontally or vertically. They appear to be formed usually as the result of shearing and infiltration of the calcite derived from the adjacent limestones. Plate XII, *B* (p. 66), shows a portion of the Paleozoic limestones on the east coast of Darby peninsula, where an intricate network of calcite veins forms a stockwork through the brecciated limestones. Although the veins are slightly more numerous in this view than in the majority of exposures, the arrangement and general characters are quite typical. Plate VIII, *A* (p. 46), already referred to, shows other calcite veins of the same general mode of occurrence near a greenstone intrusive. Some of these veins are undoubtedly younger than the intrusion of the greenstones, as they cut them or occupy joint planes in them, and it is believed that most of the veins were produced either during or subsequent to the deformation of the Paleozoic rocks.

Calcite is practically the only mineral found in the calcite veins. No sulphides or other metallic minerals have been noted in them, and they are consequently, in this region, of no economic importance.

At least two distinct series of quartz veins have been recognized in the region; in one the veins are much contorted and sheared, in the other crystalline quartz with characteristic comb structure is found. This difference in structure is to be explained by the difference in age of the two types. It seems evident that to have been crushed, sheared, and otherwise deformed the veins must have been in existence at the time of the post-Paleozoic deformation, whereas on the other hand the slightly sheared, relatively undisturbed character of the other group of quartz veins points to the fact that they were formed subsequent to that period. Although these two main groups have been recognized, it is almost certain that the older ones include veins of at least two different ages, one earlier than the Silurian and one later than the Carboniferous, but this point has not been definitely settled and will be difficult to prove owing to the great amount of post-Paleozoic deformation.

So far as can be determined the content of both classes of quartz veins are nearly identical. Sulphide mineralization is usually absent and, although a few copper or iron stains are found at places, the larger part is formed of white quartz seldom even iron stained. Both classes in places carry small quantities of gold. This has been determined mainly by chemical means, for the gold is in the native state and is usually in too small particles to be recognized by the eye. Pieces of quartz from both the older and the younger quartz veins, however, have been seen in which gold was visible. Assays from different auriferous quartz veins have yielded widely varying values, but there is no evident difference between the quantity of gold carried in the two groups. Although the gold content of the older and the younger veins does not seem to be materially different, the fact that the older ones are more shattered and discontinuous renders them on the whole less adaptable to economic development than the younger veins.

Few of the contorted and sheared veins are more than a few inches in width and are usually lens-shaped. Here and there, however, much thicker lenses have been noted, and Mendenhall calls attention [a] to a conspicuous example a few miles north of Cheenik, which is 30 feet by 10 feet by 15 feet. It is described as compact and barren, and exhibiting a brilliant fracture. Other large lenses were seen in the Darby Range and in the Bendeleben Mountains, but they seem to hold no promise of economically valuable minerals. Mendenhall also notes a vein 6 feet wide striking north and south in the sea cliff 4 or 5 miles from Rocky Point, but in this vein the quartz was rusty, as though sulphides were originally present but had been decomposed.

The younger quartz veins are less sheared and shattered than the older veins already described. It should not be concluded, however, from this statement that they have not been subjected to deformation, for they are faulted and discontinuous. Probably like the older veins they may belong to more than one period of formation, but evidence concerning this point is not conclusive. The terms "younger" and "older" quartz veins are therefore to be regarded as purely relative, though in a broad way the former are pre-Paleozoic, whereas the latter are post-Paleozoic. Some of the younger quartz veins cut the pre-Cretaceous granites so that a clue to their age is afforded. No quartz veins have been found in the more recent olivine basalts, and thus the upper limit of their age is determined.

Like the older veins the more recent quartz veins are usually narrow and seldom can be traced for long distances. They are particu-

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[a] Mendenhall, W. C., op. cit., p. 211.

larly numerous in the black quartzites and slates of the Paleozoic rocks and in that relation form an intricate network of veinlets, many of which are only a fraction of an inch in width. Sulphides, although on the whole relatively unimportant even in the later veins, are more abundant than in the older group. They are usually iron and copper pyrite, but galena, arsenopyrite, and stibnite are found. The latter minerals, however, where found in considerable quantities, as at Omilak and Bluff, are not associated with quartz veins but seem to fill fractures in the country rock.

Considering the metamorphic area as a whole, it may be stated that the mineralization is widespread, but that the veins are seldom individually continuous. The mineralization is more in the form of a stockwork or mineralized zone than in sharply defined single veins. Owing to this disseminated character of mineralization the localization of ore bodies is not pronounced, and it is believed that, if commercially valuable deposits are found, they will be more or less similar to the Juneau type of deposits.

Further consideration of the veins which have been prospected will be given in a later part of this report dealing with the economic geology of the region (pp. 127–136).

UNCONSOLIDATED DEPOSITS.

Unconsolidated deposits occur throughout the Nulato-Council region and are important because some of them contain economically valuable minerals. In the following section the distribution and general characters of the different types will be described, the economic features being left for separate treatment in the later chapter on the economic geology of the region. For this reason specific description of the different creek gravels will be omitted here and the main attention will be directed to the more general features of these deposits.

Broadly considered, the unconsolidated deposits may be divided into two classes; in one class the material is practically unsorted, whereas in the other the material has been transported, mainly by water, and deposited at some distance from the place where the waste originated. To the first class belong the talus of frost-riven material and hillside waste covering the surface of most of the upland region; to the second class belong the gravels of various origins and also, for the purposes of this paper, the glacial deposits. There are gradational phases between the two classes, but the main difference on which emphasis is placed is that the latter are in the main water sorted, whereas the former are not.

UNSORTED DEPOSITS.

As has already been stated, the main characteristic of this group of deposits is that they have been little, if at all, affected by running water. Some sorting has, of course, been effected by the gravitative, downhill creep of the material, but this is relatively unimportant. These deposits are, therefore, normally made up of angular material derived from the ledges directly up the slope from the place where they are formed, or they are the frost-shattered fragments of the country rock immediately beneath the surface.

Deposits of this sort are particularly characteristic of the uplands, where the strong temperature changes allow rapid disintegration of the underlying rock. Plate XI, *B* (p. 58), shows a typical view of this sort of deposit in the granite area north of the Kwiniuk, and might be duplicated by pictures from all parts of the field. Of course the waste is not always as coarse as is shown in this view, for the size of the fragments depends upon the physical features of the rocks from which the material was derived. Therefore, in the sandstone shale regions the float is in smaller pieces than in the places where the bedrock is granite.

When the disintegration takes place on a hillside, as shown in the plate (XI, *B*), instead of on top of a hill, the waste as it is formed spreads down the slope and forms a mantle of rock fragments similar to that shown on the hillsides across the valley in Plate III, *A* (p. 22). The foreground of this view shows the general character of this waste sheet on the near side of the valley. Waste sheets of this sort are usually coarser and thinner toward the ridge and become gradually finer and thicker toward the valley floor.

The deposits of unsorted rock waste are so universal that if they were shown on the geologic map they would obscure all the other patterns; hence they have not been represented. This course is further justified by the fact that they have no economic value and are therefore unimportant to the present study. If, then, the reader desires to reproduce the surface features of the Nulato-Council region precisely it would be necessary to imagine practically all of the area not occupied by gravels as covered by the unsorted deposits, except here and there where bedrock outcrops. Such ledges, however, probably do not form one per cent of the entire area.

DEPOSITS OF TRANSPORTED MATERIAL.

The deposits of transported material may be divided into marine deposits, nonmarine water-laid deposits, and glacial deposits. Typical examples of each of these three classes have been recognized in the field, but the gradations between the different classes and the absence of detailed investigations prevent the separation of the three groups on the map. The marine and the nonmarine water-laid deposits show examples of deposits formed at more than one time, so that these two are further divisible into older and younger gravels. The glacial deposits have not been so thoroughly studied as the others and only one division has been recognized. It is by no means improbable that with further investigation these deposits also might be subdivided. It should be noted that the terms "older" and "younger" refer to the relative age within the group and that it by no means follows that one of the older marine deposits is equivalent in time of formation to a particular example of an older deposit of nonmarine water-laid gravels. Such refined correlations must await future investigation. Broadly speaking, however, the group of older marine sediments are equivalent in age to the group of older nonmarine water-laid deposits.

MARINE GRAVELS.

Lithologically the younger marine gravels present great diversity depending in large measure upon the material of which the shore line is composed. The topography also exercises a considerable influence on the physical characters, for in the bights between headlands the materials are fine-grained, whereas near the promontories bowlders and coarse gravels predominate. Near the mouths of the larger streams the mixture of fluviatile and marine deposits is so complex that it is impossible to separate the two. On the present shore line from the mouth of the Koyuk to Cheenik the marine gravels present a great diversity, ranging from fine muds to bowlders 10 feet or more in diameter. Here and there sea stacks interrupt the continuity of the gravels so that the floor on which the present deposition is taking place is irregular. In the sheltered stretches of the coast enormous quantities of drift wood, probably brought down by the Yukon, are accumulating and are being buried as part of the marine deposits. Marine shells, except near the mouth of the larger streams, are not abundant in the deposits being formed at the present time. Garnet and magnetite sand so common along the beach from Topkok westward is almost entirely absent in the eastern part of the coast line.

Marine deposits now somewhat elevated above the position in which they were laid down and consequently belonging to the class of older gravels have been found at many places. These deposits are perhaps best shown by the coastal plain east of Norton Bay north of the Reindeer Hills. Few sections of these gravels have been made, so that their depth and character are not well known. A prospect hole near the mouth of the Ungalik was sunk nearly 100 feet without reaching bed rock. The fact, however, that bed rock outcrops at Island Point only a few miles away shows that the floor on which these sediments have been deposited is uneven.

On the east coast of Darby Peninsula old sea caves 20 to 30 feet above present sea level were recognized at a number of places and are shown in Plates III, *B* (p. 22), and XIII, *B* (p. 66), already described.

Mendenhall also observed evidence of former higher stands of the sea, for he says,[a] "On the west shore of Golofnin Bay raised gravels were observed capping the schistose bluffs at Rocky Point. From this point westward evidence of uplift is increasingly abundant and consists of terraces, high gravels, and superposed streams." From this evidence it follows that at a time not remote geologically the sea stood in places at least 25 feet above its present position, so that considerable areas now dry land were formerly covered by the sea. Therefore marine gravels are to be expected inland from the present shore and have been recognized at many places. Some of these deposits have, however, been subsequently reworked by the streams, so that their marine characters have been obliterated. There is but little question that parts of the gravel deposits at the head of Golofnin Bay and in the bight between the Miniatulik and Isaacs Point are of marine origin, but the transition between the evident marine material and the equally evident fluviatile gravels is so gradual that no line of separation can be drawn without numerous sections not now available.

Not only are there evidences of former higher levels of the sea, but at Bluff a beach line is developed several feet below the present sea level so that at an earlier time the marine gravels did not extend inland so far as they now do. This emphasizes the point that the various members of the unconsolidated marine deposits are not of the same age, but that the sea level has oscillated considerably during a long period.

RIVER GRAVELS.

Every stream in the region is forming gravel deposits and examples of this class are abundantly represented. Owing to the scale of the map, however, only the larger deposits have been shown, so that in reading the map this fact should be constantly borne in mind and it should also be remembered that even in the headwater branches of the smallest streams water-transported gravels are found. As has already been pointed out the creek gravels may be divided into an older and a younger group. These two may so grade into each other that no sharp line of demarcation can be drawn. In this report, however, the lower bench gravels up to 10 or 20 feet above the stream are considered as belonging to the younger group.

The lithologic character of the stream gravels depends very largely on the kind of rocks exposed in the valley in which they occur. Thus in the case of a small stream flowing in a valley carved in only one kind of rock the pebbles are entirely of this kind of rock, whereas in the case of the larger streams, such, for instance, as the Yukon, the

[a] Mendenhall, W. C., op. cit., p. 210.

gravels have been derived from a great variety of different rocks outcropping within the basin and show a great diversity of lithologic character. So far as has been determined almost all of the younger stream gravels are of local origin; that is, have been formed in the valleys in which they now occur. This point, however, requires considerable additional study, for similarity of rock types and the large area covered are likely to give an appearance of simplicity not justified by more searching examination. An exception to this rule is afforded by the gravels of Melsing Creek, where granite bowlders derived from the Bendeleben Mountains are intimately associated with gravels of distinctly local origin.

On the smaller streams the thickness of the gravel is only a few feet, but on the larger streams, especially those that have undergone a complex geologic history, the gravels may be more than 100 feet thick. These deeper gravels undoubtedly belong, in part, to the older ones, but as they grade directly into the present creek gravels differentiation can not be made here, and they will be described at this place. On Mystery Creek, midway between its junction with the Niukluk and the point where it leaves the hills, a shaft penetrated gravels to a depth of 102 feet. The gravels were but slightly waterworn and contained small shells in a perfect state of preservation. Bearing on this same question is the fact that in 1906 a hole was sunk midway between Bear and Fox Creeks west of Council in a bench deposit about 50 feet above the river. This drill hole reached a depth of 250 feet, all this distance being in gravel. Such a depth would make the bottom of the hole at least 50 feet below sea level. As bedrock outcrops within 2 to 3 miles of this place, this thick deposit of gravels strongly suggests the probability of having been formed by an earlier stream which carved its channel when the land stood relatively higher with respect to the sea than it does now.

Another deep gravel deposit has been located in the hills west of the Koyuk near camp B16. At this place a shaft 192 feet deep was sunk all the way through well-rounded gravels. The bottom of the deposit is a considerable distance below sea level and points to a change in respect to sea level since the channel was carved. This channel was probably due to the effusion of some of the post-Cretaceous lavas which obstructed a former stream course, but the fact that the bottom of the channel is far below sea level can be explained only by assuming that since it was formed the region has been relatively depressed. A further description of this deposit is given on pages 110–113.

Although practically nothing is known of the depth of bedrock in the bottom of the Yukon Valley, there are many things which lead to the conclusion that the gravel filling may in places be very thick. This is also true of the Koyukuk and of the lower parts of the

Kateel, the Gisasa, and other large tributaries. It is possible that these deeper gravels are not solely of fluviatile origin, but data are too few to permit a final analysis of the problem.

In addition to the gravels known to belong to an older group, because they underlie the present stream gravels, there are also older gravels whose age is determined by the fact that the stream has cut its valley down into them. In other words, there are bench deposits which mark either a relative uplift of the land or a change in the erosive power of the streams in the recent past. In elevation above the adjacent streams the benches range from only a few feet to several score feet, the higher, of course, being more obliterated by having been exposed to erosin a longer time than the lower.

Russell,[a] who ascended the Yukon in 1890, called attention to certain obscure indications of terraces or sea cliffs at an elevation of 1,500 or 2,000 feet on a number of the hills below Nulato. In traversing these ridges in 1909 the party found no traces of gravel at such high elevations, and it is believed that the appearance of nearly horizontal benches is due to the beveling of the stratified rocks of the Cretaceous, which outcrop in these hills. Lower down, however, at an elevation of about 50 feet above the river, silts and sands form pronounced benches. Although these deposits have not been studied in detail, their position and topographic expression suggest that they mark former river-laid gravels and sands subsequently dissected by the relative down cutting of the present river.

Bench gravels are found in the Shaktolik Valley and were especially noted near camp A10, where a broadly open older valley floor covered with gravels has been dissected by the narrow rock-walled canyon of the present stream. Much of this bench gravel is heavily iron stained. This feature was also noted at several places farther downstream near camp A13. From the topographic similarity it is probable that bench deposits corresponding to those noted on the Shaktolik occur also in the Gisasa and Kateel valleys, but they were not searched for.

In southeastern Seward Peninsula bench gravels are by no means uncommon along the lower slopes of many of the valleys. The deep holes on Alameda Creek and on the Niukluk were started to explore some of these bench deposits and part of the other gravels belonging to this class, but as they grade insensibly into the lower gravels they have been described with the older ones. There are, however, many places, as, for instance, along Ophir Creek, in the Council region, where bench gravels only a few feet thick have been found. Some of these are auriferous and some are not.

[a] Russell, I. C., Notes on the surface geology of Alaska: Bull. Geol. Soc. America, vol. 1, p. 139.

The geologic significance of the finding of bench deposits at different elevations widely distributed throughout the entire Nulato-Council region is that there have been frequent oscillations of the streams with respect to sea level. These oscillations may have been due in part to climatic changes, but in part they are to be accounted for only by assuming movements of the land with respect to the sea. Although the presence of benches above the streams at the present time shows that there has been an uplift of the land, the fact that some of the larger streams have their rock-cut floors below sea level shows that the sum of the recent upward movements indicated is not at present equal to the sum of the downward movements in the recent past.

A peculiar type of gravel deposit, in part fluviatile in origin, but probably also produced by other agencies, is found in the basin lowlands, such as Death Valley and the Fish River lowland north of the gorge. Sections in these basins have not been made, and little can be determined from the examination of their surficial aspects. Mendenhall states [a] that the Fish River lowland is filled with deposits, "coarse near the borders and fine near the center of the basin. The depth of this filling is purely conjectural, but presumably is not great. No islands of bedrock exist within it, as far as known, but sand and gravel prominences, rising in some instances 30 or 40 feet above the general level, are abundant over it, and are interpreted as remnants of a slightly higher level generally destroyed by the meanderings of the stream." Brooks [b] attributed the origin of these basins to warpings of the crust, whereby depressions were formed, which have been subsequently filled. So long as the topography of the floor on which the gravels rest has not been determined, it seems unsafe to attempt an explanation of their origin. The fact, however, that the uplands are so abruptly cut off by the lowland suggests that the basin is mainly due to erosion rather than to deformation. The question of the origin of the basin is not important in this discussion, for under either view the flats are believed to have been formed by the filling of a depression either by fluviatile or lacustrine deposits.

Owing to the high northern latitude, many of the deposits are permanently frozen, and as the presence or absence of frost in the ground has an important effect upon mining enterprises a general statement of the distribution of the ground ice may be made. Generally the older gravels are permanently frozen and some of the bench deposits contain beds of clear ice in places a score or more feet thick. So far as is known, the presence or absence of trees on the gravels is no sure indication that the ground is thawed, for many

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[a] Mendenhall, op. cit., p. 207.

[b] Brooks, A. H., The geography and geology of Alaska: Prof. Paper U. S. Geol. Survey No. 45, 1906, p. 282.

instances are known of trees of large size growing on frozen ground. For instance, at Nulato, as Russell[a] states, a well 25 feet deep went through clay and sand beds, which were frozen solid with the exception of certain dry sandy layers, and yet spruce was abundant in the neighborhood before it was cut off. Although most of the older gravel deposits are frozen, those near the present streams are usually thawed. Whether this condition is due to the better drainage of the present stream gravels which prevents the formation of ice is not known. There is a strong suggestion, however, that the frozen condition is due to past climatic controls and is in a way an inheritance rather than a process now in progress. This possibility receives some support from the distribution of ground ice in the marine gravels. In the present beach deposits permanent frost is unknown, whereas in the older ones it is almost universally present.

GLACIAL DEPOSITS.

Glacial deposits are limited to the mountain regions, and there is strong reason for believing that the Nulato-Council region has not been covered by a large ice sheet in sufficiently recent time to have had any effect on the general topography or on the unconsolidated deposits. Near the Bendeleben and Darby highlands, however, there are indisputable evidences of former valley glaciers of the alpine type. Deposits formed by this agency are of three kinds—in one the materials are unsorted and are dumped in irregular heaps essentially as they were deposited when the ice melted away; in another the glaciers obstructed the normal drainage and thus formed lakes on which ice-rafted bowlders were transported and deposited; in the third the morainic material was transported away from the melting ice by water and so, although originating through glacial action, the present form of the deposits is characteristic of stream deposition.

A particularly clear example of the unsorted morainic material has been reported by Henshaw in the Pargon River valley. At the edge of the mountains where the stream debouches into the Fish River lowland a long spur on the east side of the valley marks the margin of a former glacier. West of this stream, near the same place, the low divide between the Pargon and Ophir Creek is also formed of morainic material, with small kettle holes or depressions irregularly distributed over its surface. Farther up Pargon River a moraine from McKelvie Creek extends out into the main valley and shows characteristic morainic topography. This same condition is also true of Helen, Decatur, and many of the other tributary creeks. The absence of frontal moraines marking the recessional stages of the main glacier is probably to be explained by assuming that the

[a] Russell, I. C., op. cit., p. 129.

material was washed away by the water from the melting ice and not allowed to accumulate. According to this interpretation, part of the gravels of the Fish River lowland and of Pargon River are of glacio-fluviatile origin. The presence of granite bowlders in the gravels of Melsing Creek is probably due to this period of glacio-fluviatile activity when the ice stood sufficiently far south to allow a discharge from its front across the low divide at the head of Melsing and Ready Bullion creeks.

In the upper Niukluk Valley, near Mount Bendeleben, glacial deposits were observed, in 1908, on both the north and the south sides of the range. Moraines are also reported on Baker Creek and Oregon Creek, so that glacial phenomena are observable throughout the Bendeleben Mountains; but the consensus of opinion by all observers is that these glaciers were never very extensive.

Around the higher parts of the Darby Range there are also strong evidences of local glaciation in the past. Marginal moraines, however, have not been recognized beyond the front of the hills and it is probable that they were not deposited. Whether their absence means that they were not allowed to accumulate because of the rapid removal of débris by the water flowing from the front of the glaciers or whether the ice did not extend beyond the front of the mountains has not been determined.

Near camp C13, where the branch of the Etchepuk makes an abrupt angular turn from a southwest to a northwest course, there is abundant evidence of a morainic ridge which is probably responsible in part for the sharp bend in the stream. Although there is no clear proof of the conclusion, it is believed that at one time there may have been a discharge of this branch by way of the Kwiniuk basin. Although the evidence is conflicting, there is a possibility that the Fish River lowland also may be due to glaciation, but this interpretation requires much more detailed investigation and is advanced with many reservations.

That glaciation has considerably modified the topography within parts of the Darby Range by the deposits of glacio-fluviatile material is well shown by the ridges south of camp C11, which form part of the Etchepuk divide. These ridges are mainly due to the work of glaciers that occupied the valleys on either side, but the presence of water-worn cobbles intimately associated with angular ice-transported débris shows that both agencies were operative in the deposition of the material. From the topography it seems probable that this morainic deposit accumulated, as is indicated in fig. 7, where the tongues of ice are represented by CC, with nunataks, or islands of the underlying rocks (AA), separated by low saddles now filled with moraines (BB). The elevation of the top of the morainic material above the floor of the present stream is about 400 feet. East of this point and farther up the ridge there is no evidence of glacial deposits, and bare rock ledges outcrop.

All of these examples of glaciation have been taken from the west side of the range, the one to which the main attention of the party of 1909 was paid. Apparently glaciation is more notable on this side than on the eastern, for Mendenhall says:[a] "Many of the higher areas have not been examined in detail and it is possible that small local glaciers may have existed in the heads of some of the valleys, but no evidence of their existence was gathered during the summer, and views into the mountains from levels but little below their highest points revealed no forms suggestive of ice work."

AGE OF UNCONSOLIDATED DEPOSITS.

A consideration of the unconsolidated deposits as a whole indicates a great diversity of age, represented by the different types. It is not possible as yet to correlate these various deposits definitely, but in a broad way they are more or less closely related; the larger part are Quaternary, but probably none are older than the upper Tertiary. From that as the maximum age they grade down to the present day as the minimum. Assuming that the period of maximum glaciation was practically contemporaneous in the northern hemisphere, the glacial deposits already noted may be regarded as Pleistocene. Certain bench deposits contain mastodon and mammoth bones, which show that they, too, may have been deposited during Pleistocene time. Gravels containing bones of this age have been reported in the Buckland Valley, near Candle, on Ophir Creek, and along the Inglutalik, where they are numerous.

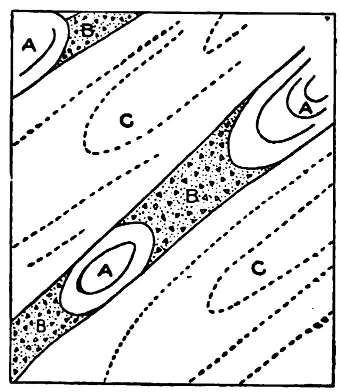

FIGURE 7.—Diagram showing relations of glacial material on Etchepuk divide. (A, Rocky knobs. B, marginal glacial deposits. C, Valley glaciers.)

From the accounts of Henshaw, the well-recognized moraine, at the point where the Pargon River leaves the hills, has been deposited on top of the gravels of the Fish River lowland. Whether this means that all these gravels are older than the glaciation or whether the recognized moraine may only be one of the recessional stands of the ice after a much farther southward advance has not been determined, so that no statement of the age of the two types of gravel can be made. From the meager evidence, however, it seems probable that these gravel-plain deposits are in part contemporaneous with the

[a] Mendenhall, W. C., op. cit., p. 208.

glacial deposits and in part older than the period when the ice stood at the point where Pargon River leaves the hills.

Concerning the age of the marine gravels there is considerable uncertainty. Direct observations in this actual area reveal no evidence, but from analogy with better-known parts of the peninsula there are grounds for regarding them in part, at least, as late Tertiary. The evidence bearing on this point is as follows: In the coastal plain near Nome, which topographically resembles the coastal plain east of Norton Bay, fossils which, according to Dall, are of Tertiary age have been found; furthermore, glacially striated rocks at Nome in the upper part of the deposit indicate that this part was contemporaneous with the period of glaciation. In other words, the lower part of the coastal-plain deposits may be Tertiary and the upper part Pleistocene, and perhaps still more recent gravels rest on top, deposited as the former sea bottom emerged from the water and took on its present relation to sea level. As has been already pointed out, however, a long time is required for the various oscillations of the coast, so that the marine deposits have a considerable range in age.

STRUCTURAL GEOLOGY.

From the foregoing description of the various rocks in the Nulato-Council region it is evident that the structures they present are complex. Already the facts have been brought out that there are a group of metamorphic rocks which were dynamically deformed before the laying down of the Cretaceous sediments, that the Cretaceous rocks have themselves been folded and deformed, and that, latest of all, there have been undeformed lava flows and gravel deposits. It is thus evident that at least two periods of mountain building and deformation have affected the older rocks, and that their present distribution and characters are the resultants of these perhaps opposed actions. These actions have produced enormous dislocation and folding, which can only be vaguely realized and which can not be represented in section except so diagrammatically as to obscure the facts. Furthermore, precise details of complex structure can not be gained on an exploratory survey. It has seemed best, therefore, not to draw cross sections with the appearance of finality, but rather to call attention to the geologic maps (Pls. V and VI, in pocket), from which sections may be constructed. In this way the hypothetical condition will be more clearly discriminated from the actual facts.

The large scale structural features of the region are folds and faults. Many examples of each were observed in the field, and many others must be assumed in order to explain the areal distribution of the various rock groups. In the areas of metamorphic rocks the structure seemed to be simple in places where outcrops were scarce, but was found to be very complex in places where outcrops were frequent or continuous, as, for example, along the seacoast of the Darby peninsula; profound disturbance alone could explain the facts there revealed. In the areas of post-metamorphic rocks, on the other hand, the structures, although deformed, showed larger scale and consequently less complex relations. For this reason the two areas may be treated more or less independently.

The folds and faults produced by the post-Cretaceous deformation are most strongly marked in the Nulato-Norton Bay region. Here the predominant structure trends northeast-southwest and is very pronounced. This structure has had a marked effect upon the

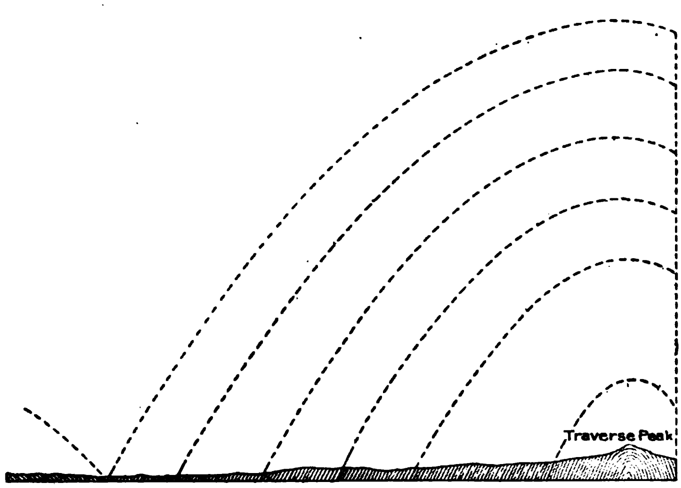

FIGURE 8.—Diagrammatic section west of Traverse Peak.

distribution of the topographic features, such as ridges and valleys, which are dominantly parallel to this direction. Although the trend of the ridges is undoubtedly due to the structure, the surface in no way corresponds to the surface of the old folded structure; for, although some of the ridges are anticlinal, many are synclinal. Such a condition, of course, would not be produced unless long-continued erosion had dissected the hills. In the part of the divide between the Yukon and the Norton Bay drainage near Traverse Peak the structure is distinctly anticlinal, but the present surface of the hills must be many thousand feet below the former surface. Figure 8 shows in diagrammatic fashion the observations made eastward from near the forks of the Inglutalik, 2 miles below camp B8, to the top of Traverse Peak. The observed dips are indicated by the heavy lines, whereas the implied consequences are shown by dotted lines. In this figure the vertical height of the structure is undoubtedly somewhat too great, for faults of greater or less displacement are to be expected. While, therefore, the diagram is not to be taken too literally, it indicates that an enormous cover has been removed; hence the divide is an erosional rather than a constructional feature. In this connection it should be pointed out that the thickness of the Shaktolik group, indicated in this diagram, can not be taken as indicating the total thickness of the cover, for the top of the group is not exposed near the forks of the creek in the bowl of the syncline, and there is no evidence as to the distance to the upper surface of the group that has been removed by erosion.

Considered in a broad way the region from the Buckland-Kiwalik divide eastward to the Kaiyuh Hills is synclinal, the folding having a general northeast-southwest trend. It is complicated by numerous folds and faults, so that when examined in detail its larger features become obscured, and in general it shows a rim of the oldest Cretaceous rocks near the margins, with younger rocks toward the center of the synclinorium. In the central part of the area the post-Cretaceous deformation has been expressed mainly by folding, but toward the western part of the region, at least, faults of enormous throw seem to have resulted. This fact is clearly shown by the relation of the Ungalik conglomerate near the Tubutulik. This block, isolated from the rest of the Cretaceous area by a belt of schistose rocks of Paleozoic age or older, appears as a down-faulted remnant of the former extension of the Ungalik conglomerate of the East Fork of Koyuk River. So also the Cretaceous area west of the mouth of the Koyuk seems to be an inset block of sandstone dropped down so far that the conglomerate which should underlie it is not exposed. The absence of the conglomerate at this place shows conclusively that the beds could not have been folded into their present condition, but must have been inset by faulting. No estimate of the displacement represented by this fault was obtained, but it was at least many hundred feet and was possibly several thousand feet.

As suggested in the preceding paragraph, it is believed that many if not most of the larger faults in the area dominantly occupied by the Cretaceous rocks were produced at the same general period as the folding in the central part of the region. Folds passing into faults are well-known phenomena, and it seems reasonable that where the deformation was greatest the beds would be more apt to rupture and produce faults. That the regions outside of the great Cretaceous area were the most uplifted is indicated by the fact that sediments of this age have been removed by erosion more extensively than in the Nulato-Norton Bay region. It is not believed that the absence of Cretaceous rocks over much of the area of metamorphic rocks which form the rim of the present basin is owing to their not having been originally deposited there. The reason for this belief rests on the inset blocks on the Tubutulik and at the Ramparts of the Yukon as well as at many of the less well known localities. It seems that these blocks point conclusively to a former much greater extension of this rock system, which has been gradually decreased as erosion removed the higer parts and exposed the underlying rocks. As to the position of the former shore line of the maximum extent of the Cretaceous sea there is no known evidence, and it is doubtful whether proof can be obtained, as erosion has so extensively removed the traces.

To return to the faults in the Cretaceous area—it has been suggested that many of the larger faults have been the result of the post-Cretaceous deformation, and the reasons for this belief have been stated. Although the validity of this argument may be questioned, as it rests so much on hypothesis, there can be no doubt that certain faults belong to this period. Numerous examples were observed along Shaktolik River where closely appressed folds have been broken and faults have been produced by the deforming forces. It is a notable fact well shown by the excellent exposures along the canyon walls of the Shaktolik that, where the deformation is most intense, as indicated by the close folding, faults are most numerous. Of course, it is only at intervals that the age of these faults with respect to the folding can be determined by direct observation. The intimate relation, however, of faulting to areas of close folding and the observed passage of folds into faults make it almost certain that much of the folding and faulting were contemporaneous.

That there has been faulting in the Cretaceous area subsequent to the main period of deformation is clearly shown by the fact that faults have been observed cutting the post-Cretaceous dikes which form apophyses of the Christmas mountain intrusion. Faults of this age were observed near camp A16, on the Ungalik, and there was evidence that larger movements had taken place elsewhere. It is to be borne in mind, however, that the opportunities for obtaining data on the age of the faults are infrequent, and it is by no means improbable that faults later than the post-Cretaceous deformation may be more common and widespread than the single faulted area noted indicates. So far as known, however, it is certain that none of the later faults exercise a direct effect on the present topography.

As has already been pointed out, the period of post-Cretaceous deformation was one of mountain building, and its effects were not confined to the Cretaceous area between the Yukon and the Koyuk, but were extended to the already greatly deformed rocks of Seward Peninsula. Traces of this folding may still be recognized in the dominant north-south trend of many of the structures. An illustration of this trend is seen in the band of Paleozoic rocks along the east side of the Darby Range and also in the various limestone bands west of this range. Although this direction is also the trend of the Darby Range and of the highland of the Buckland-Kiwalik divide, the rocks in both of which are older than the Cretaceous, it seems probable that this form is a post-Cretaceous feature, so that the intrusions were not controlled by this structure. According to this explanation the Darby and the Kiwalik hills are due to the post-Cretaceous deformation, and the fact that the igneous rocks of the two areas are not continuous or aligned gives support to this interpretation. It is not intended, however, to assert that these hills necessarily mark the axes of the deformation, for it is believed that these areas are highlands mainly because the rocks of which they are formed have been strengthened and made resistant by the intrusives which characterize them.

A difficulty in the way of the acceptance of this interpretation is the undeformed character of the granites and other igneous rocks of these areas. Although on the face this is a vital objection, the incontrovertible fact that these rocks form the bowlders in the Ungalik conglomerate makes them certainly older than the post-Cretaceous deformation. Either, then, these rocks were unaffected during this period of mountain building or else they passed through it without marked folding and shearing. That a belt of rocks, averaging in width only about 6 miles and nowhere over 12 or 14 miles wide, should have withstood pressures great enough to fold perhaps 6 miles of Cretaceous sediments into great waves as one would fold the leaves of a magazine is almost inconceivable. It seems far more probable that the deformation that occurred in this part of the field was characterized by faults rather than by folds. According to this explanation great blocks practically undeformed may have been uplifted and oriented in a north-south direction without having been folded or without having had pronounced shearing induced.

With such pronounced post-Cretaceous deformation noted so widely throughout the region, it is evident that the untangling of earlier structures is possible only by the most detailed investigation. Inasmuch as such studies have not yet been made, it follows that interpretations are to be regarded as tentative and as indicating the kind of structures to be expected rather than as stating the precise structure at any particular locality. In order to emphasize the complex character of some of the pre-Cretaceous deformation a few examples of field observation may not be out of place.

Plate XIII, *A*, shows one of the closely appressed folds in the immediate neighborhood of the Omilak mine and very clearly illustrates the point in hand. This illustration is, of course, only one of the smaller folds, for, as is indicated by the hammer, which is about 18 inches long, the outcrop is only about 10 to 12 feet high. It should also be noted in this view that although the folded character of the

A. FOLDED LIMESTONE NEAR OMILAK MINE.

B. FOLDED AND SHATTERED LIMESTONE ON OPHIR CREEK.

beds is very clearly shown in the central and left-hand portion of the picture, the beds on the opposite sides of the axis in the right-hand portion are so nearly parallel that except under favorable conditions of exposure the divergence might be attributed to minor faults or might even pass undetected.

Where the beds are so closely folded it is evident that it is very difficult, if not impossible, to distinguish between the two or more periods of deformation known to have affected the region. For instance, the fold shown in Plate XIII, *A*, has a strong pitch to the west—that is, away from the point of view. Whether this pitch is due to the same deformation which overthrew the fold toward the north (to the right) or whether the overturned fold has itself subsequently been folded parallel to a north-south axis is not known. Figure 9 shows in diagrammatic manner the conditions probably existing at this place, the right-hand part of the diagram representing the part of the area shown in Plate XIII, *A*. As the north-south folds of the post-Cretaceous deformation are the latest mountain building in the region, it follows that the east-west trend noted in the vicinity of the Omilak mine preceded that period and was later deformed by the forces producing the north-south trend. On the other hand, it is entirely within the bounds of reason to suppose that in a period of deformation such as that which followed the laying down of the Cretaceous deposits the dynamic forces would not be equal over the entire area; hence the sag shown in the diagram might occur at a place marking inequality of the deforming force.

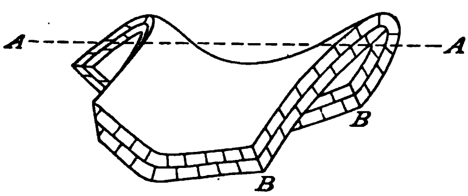

FIGURE 9.—Diagram showing folding in two directions.

Whatever the final determination may be as to the origin of this structure, the fact remains that it is by no means uncommon in the region. The irregular distribution of the different formations seems to suggest a structure of this kind. For instance, if the present erosion surface be indicated by a plane passing through the dotted line AA in figure 9, it is evident that the limestone bed BB would be exposed in the field by two isolated outcrops in which the fold, if it was as closely appressed as the one shown in Plate XIII, *A*, would probably escape detection, owing to the close parallelism of the two limbs.

The reverse of the condition shown in figure 9 might also occur where the field relations would be as though the diagram were looked at upside down and the erosion surface were still represented by the dotted line AA. Under this condition only the synclinal bowls where the rocks had been folded down lowest in the latest period of deformation would be preserved. This condition might, of course, expose either anticlines or synclines of the earlier period of deformation, so that a single observation would afford no conclusive idea of the relations.

With each subsequent folding some of the earlier features are obliterated and structures formed in the previous period of deformation become contorted. Plate XIII, *B*, shows a limestone outcrop about a quarter of a mile above Dutch Creek on Ophir Creek in the Council region that has very evidently been folded so that now the dominant structure is standing vertical. When this exposure is studied in detail it is evident that the thing which has been folded is a previous cleavage and not the bedding. In places, of course, the bedding corresponds to the cleavage, but in this picture it is evident that it is a cleavage that has been folded. This indicates that two periods of folding have taken place; in one the cleavage was produced, and in another it was folded.

Examples of this twofold structure are to be seen in all parts of the field and are not limited to any particular kind of rock, except that two structures are never seen in the later igneous rocks nor in the Cretaceous sediments. Evidences of two structures are particularly notable in the schists and limestones, but the black quartzites of the Paleozoic rocks seem to have fractured rather than folded in the post-Cretaceous period of deformation. Usually in the schists the later folding is recognized by minor transverse plications. The small hand specimens are the miniatures of the larger features, and the reason for the difficulty in recognizing the larger ones is the complexity of the structure and the absence of clearly distinguishable horizons in the schist complex. On the 1,200-foot hill east of camp C4 almost every piece of float gives striking illustration of this double plication.

Of the existence of the two periods described there can be no doubt, for they have been recognized not only in this field but in many other parts of Seward Peninsula. Moffit, who studied the region to the north where the rocks are similar in many respects to those found in the southeastern part of the peninsula, says:[a]

> This complex (the metamorphic group), both sedimentary and igneous in origin, was affected by the two movements mentioned, which acted in very different directions. One produced a structure in which the axes of the folds extend in an east-west direction, and is most plainly expressed in the uplift constituting the Kigluiak and Bendeleben mountains. * * * This east-west structure corresponds in the direction of its folds with the main structural lines of the whole of western Alaska, and is believed to have been produced before the deposition of the coal beds; that is, before Cretaceous or lower Tertiary time.
>
> The second movement resulted in the production of folds whose axes have a general north-south direction and are the dominant structural feature of the northern portion of the peninsula.

[a] Moffit, F. H., The Fairhaven gold placers, Seward Peninsula, Alaska: Bull. U. S. Geol. Survey No. 247, 1905, p. 35.

It has already been suggested that the schists which underlie the Paleozoic rocks were probably deformed prior to the deposition of that member of the stratigraphic sequence and that the later rocks lie unconformably upon them. This is a difficult thing to prove and is advanced tentatively. There is no place where the underlying and the overlying rocks occur so intimately associated that the possibility of faulting is precluded, and, although the underlying rocks are much more schistose and apparently more deformed, there is necessarily the uncertainty as to the weight that should be given to this evidence when applied to lithologically different rocks. In spite of these objections it is believed that there was a period of profound pre-Silurian deformation. Definite proofs of this event have been, in the main, removed by the two subsequent periods of mountain building, but the constant greater metamorphism of the supposedly older schists, the field relations of the two groups, and the presence of certain structures in the older schists not found in the Paleozoic rocks lead to the conclusion that there was a period of pre-Silurian deformation.

If this hypothesis proves to be correct, it follows that an exceedingly complex arrangement of the lithologic members of the older schists is to be expected, and that the final determination of the succession in that group will be accomplished with the utmost difficulty. For the purposes of this paper, however, it will be sufficient to point out that the effect of each period of deformation has been to make the distribution of the older rocks more and more irregular, and, if the term may be applied to distribution, smaller "textured." As to the trend of the deformation of the oldest folding, there are no data available on which to base even an approximation.

HISTORICAL GEOLOGY.

To one who has followed the preceding descriptions with geologic insight the successive events which occurred in the region have already been given. As the facts for making a relative chronology, however, have been scattered through many pages, it seems desirable to collect these details into sequential order which shall give an epitome of the geologic history of the Nulato-Council region.

The oldest recorded event from which a start can be made was the laying down of quartzose and calcareous sediments over much of what is now western Alaska under presumably marine conditions. No definite age for this event can be given. It was, however, undoubtedly earlier than the Silurian. From the evidence secured by Kindle in the York region of western Seward Peninsula, where the Ordovician and Upper Cambrian seem to form a continuous relatively uninterrupted sequence overlying similar rocks, there is some warrant for considering the oldest rocks as possibly pre-Cambrian. This suggestion as to the age is to be regarded only as a working hypothesis and is by no means definitely proved.

After the deposition of these sediments there were probably some veins formed which are now represented by the knotted and contorted quartz strings found in the older schists. Either coincident with this venation or following it, probably the latter, a period of mountain building ensued in which the quartzose and calcareous sediments previously deposited were consolidated and deformed and cleavage was probably developed. Erosion followed and sediments from this old land were carried out and deposited in the sea. This process must have continued for such a long time that the highlands were reduced by erosion and the region subsequently became depressed below the marine waters, for the rocks formed of the waste thus washed from the land were apparently deposited unconformably on the underlying rocks. If the tentative assumption of the pre-Cambrian age of the oldest sediments is correct, this period of mountain building may mark the gap between the Paleozoic and the pre-Paleozoic. In this period undoubtedly many oscillations and minor deformations may have occurred which are now unrecognizable.

After the period of mountain building the material eroded from the land mass was deposited in the marine waters off the coast. The land from which this waste was derived was remote from the area under consideration, for the sediment derived from it that now covers part of Seward Peninsula was laid down as limestone. In the Nulato-Council region this deposition corresponds with the laying down of the Paleozoic rocks. In the western part of the peninsula, however, as has already been pointed out, there are limestones containing Cambrian and Ordovician fossils, and as there is no known break between these limestones and the Silurian-Devonian-Carboniferous (?) rocks of this region it is assumed that the period of deposition may have continued practically uninterruptedly from the Cambrian to the Devonian or Carboniferous. During most of this time limestones were being laid down, but the intercalation of highly quartzose carbonaceous sediments, such as those now found near Mount Kwiniuk, indicates movements of the sea floor and changes in relation to the source of waste supply.

After the deposition of the Paleozoic rocks there was probably an uplift, for the next event recorded was the intrusion of greenstones, some of which formed surface flows. Such flows could hardly have taken place while the limestones were being laid down, and it is therefore necessary to believe that a part of Seward Peninsula was at that time dry land. This period of greenstone intrusion was well marked through many parts of Alaska and has been recognized not only in Seward Peninsula, but also in the northern part of the

Koyukuk, in the basin of the Melozitna, and in the Kaiyuh hills. If the extrusions of greenstone materials took place on land they must have unconformably overlain the older rocks. In the Nulato-Norton Bay region none of the effusive types were recognized, but farther west effusive character was strongly suggested by the exposures in the Solomon-Casadepaga quadrangles. In the central Yukon region the age of the greenstone intrusion is Devonian. For this reason it is possible that in the determination of the fossils from the sedimentary rocks as either Devonian or Carboniferous, preference should be given to the older rather than the younger system. In the Copper River region and in southeastern Alaska, on the other hand, a period of greenstone effusion has been described as Carboniferous or later, so that correlation by analogy is inconclusive.

With the intrusion of the greenstones there was some local or contact metamorphism of the rocks they penetrated, but the effects were slight. There was also the formation of some veins, but many of the older veins were already in the Paleozoic rocks before the intrusion by the greenstone, for in places the veins are abruptly cut off by the later rock. With the greenstone probably a little mineralization was introduced, but its effects upon the metalliferous resources of the region were slight.

After the formation of the greenstones a period of mountain building ensued in which the previously formed rocks were metamorphosed dynamically and profoundly faulted and folded. When this occurred can not be told with definiteness owing to the uncertainty of the ages of the Paleozoic rocks and the greenstones. From the evidence afforded by other parts of Alaska there are two dates to which the deformation may reasonably be assigned—one is in the late Devonian, and the other is in the early part of the Mesozoic. If the Devonian instead of the Carboniferous age of the sedimentary rocks is assumed, it follows that either of these periods will fulfill the requirements of the field evidence. If, on the other hand, however, the upper part of the deposits is Carboniferous it is evident that the period of mountain building following the deposition and consolidation of the Paleozoic sediments and their intrusion by the greenstones must have been the one occurring in the Mesozoic. No conclusive evidence on this point has been obtained, and the question must still remain an open one.

As a result of the deformation, the rocks were cleaved and folded and probably high mountains were formed. As soon as they were formed, erosion began to wear them down and to transport the material toward the sea. No clear idea is possible of how long this process continued uninterruptedly, for the only part of the Mesozoic represented by stratified rocks in this field is Cretaceous. An interruption occurred some time after the mountain building and prior to the deposition whereby igneous activity became dominant. There is no evidence as to whether during the early part of this vulcanic cycle the region was land or was beneath the sea, but for the purposes of the present report this is not of great importance.

The first recorded intrusion of this period was the formation of diorites, which were subsequently intruded by granites, and these in turn were intruded by other diorites. Although these various phases could not have been formed within a short time of each other (for each of them had cooled and consolidated sufficiently before the next succeeding intrusion so that they broke into angular fragments), from a geological standpoint they were closely associated in age and may be considered as a unit. Evidence as to the age of these rocks is afforded only by analogy with other parts of Alaska. In the Matanuska-Talkeetna region of south central Alaska, Knopf and Paige determined the age of the great granodiorite-diorite intrusions as later than the Middle Jurassic and earlier than the deposition of the late Jurassic strata.[a] The Wrights in southeastern Alaska stated that, although the date of the major period of intrusive activity (the time of the Coast Range intrusion) was in doubt, it continued at least until late Middle Jurassic time.[b]

Although long-range correlations of this sort are clearly liable to gross errors, the absence of other data is sufficient justification for tentatively accepting the only available facts at hand. On this assumption the most reasonable age determination of the intrusives of the Darby and Bendeleben mountains is that they are Middle Mesozoic.

In the section dealing with the descriptive geology of the pre-Cretaceous igneous rocks it was stated that in the Kiwalik-Buckland divide there were ancient effusives along the flanks of that highland. It is practically inconceivable that effusive rocks of geologically the same age as granular intrusives should occur in contact with those intrusives. The granular rocks by their texture require relatively slow cooling under considerable cover. It follows, therefore, that when the intrusives of the Kiwalik-Buckland highland were injected there had been a considerable thickness of strata over the region, which was removed before the effusion of the older lavas. No precise measure of the time required for eroding the superincumbent rocks can be made, but it must have taken a long time. After erosion had exposed the plutonic rocks of the mid-Mesozoic, andesitic lavas were extruded.

During the latter part of this period this portion of Seward Peninsula, at least, must have been land. Gradual submergence occurred

[a] Paige, Sidney, and Knopf, Adolph, Geologic reconnaissance in Matanuska and Talkeetna basins, Alaska: Bull. U. S. Geol. Survey No. 327, 1907, p. 20.

[b] Wright, F. E. and C. W., Ketchikan and Wrangell mining districts, Alaska: Bull. U. S. Geol. Survey No. 347, 1908, p. 76.

and marine waters beat against the shore forming a heavy conglomerate which, as time went on and the shore line gradually encroached farther and farther on the land, was buried in the deeper parts of the basin by finer sediments. At no time, however, was the water in the basin very deep, for mud-flat markings and cross bedding are observable at many places. Probably by stages more or less equal with the filling of the basin with detritus the bottom sank until a great thickness of sediment was deposited. Where the farthest encroachment of the sea on the land occurred is not known, but marine waters must have covered the larger part if not the whole of what is now Seward Peninsula. In this sea the deposits accumulated and covered the pre-existing topography that had not been effaced by the beat of the sea upon it.

The geologic age of the sediments deposited during this period is Cretaceous. As has already been stated, on page 56, the Ungalik conglomerate at the base may be Lower Cretaceous, but the upper part, or Shaktolik group, contains no fossils other than of Upper Cretaceous age. In other parts of Alaska there has been reported a pronounced break between the Upper and the Lower Cretaceous and the two are in uncomformable relations. In this province no break was noted. If, however, subsequent studies should show a period of diastrophism between the Upper and the Lower Cretaceous it would seem rather conclusive evidence that the Ungalik conglomerate is of Upper Cretaceous age, for the fossil evidence which seemed to indicate a Lower Cretaceous age is very weak. Under such conditions the Lower Cretaceous would be represented in Seward Peninsula by the erosion interval at the base of the Ungalik conglomerate.

Succeeding the period of Cretaceous deposition was the last epoch of mountain building. By this deformation enormous folds and faults were produced which must have made mountain ranges of great height. There is no direct evidence as to the time when this folding occurred. From analogy with other parts of Alaska, however, it is known that there are two possible ages to which the epeirogenic movements may be referred. In southwestern Alaska the Kenai or upper Eocene is unconformable on the Upper Cretaceous.[a] This unconformity is marked by a break in faunas rather than by mountain building, but the fact that in places the Kenai is known to rest directly upon the Jurassic indicates a long period of changes. The other period to which the great orogenic movements of the post-Cretaceous may be referred is later than the deformation of the Kenai. There is but little to show which of these is the correct correlation, for there is no Kenai in the region studied. With full

[a] Stanton, T. W., and Martin, G. C., The Mesozoic section on Cook Inlet and Alaska Peninsula: Bull. Geol. Soc. America, vol. 16, 1905, p. 410.

recognition of this uncertainty it is believed that a pre-Kenai age for the period of orogenic movement, which closed the Cretaceous deposition, fits more of the known facts than any other interpretation. According to this hypothesis the larger outlines of the geology of western Alaska were marked out before the Kenai and the sediments of the latter period were deposited mainly on the eroded surface of the earlier rocks and mostly as fresh water deposits.

After the great post-Cretaceous deformation, intrusion of granular rocks, such as those of Christmas Mountain, occurred. It is unsafe to assign a more specific age for this period of volcanism than the middle Tertiary. Whether the mountain building was closed before the intrusion is not definitely proved. The fact that some of the dikes from the Christmas Mountain mass are faulted shows either that the deformation had not entirely ceased or that the dikes were formed at a later time.

With the conclusion of the period of granular intrusions and of the great post-Cretaceous deformation, the region as a whole has been a land area subjected to erosion which has continued down to the present time. An enormous amount of erosion is indicated before the next recorded event in the history of this complex region. As a result of this erosion valleys were cut and the region was reduced from a mountainous country to one having something like the present topography. Then volcanic activity began and continued spasmodically from the later part of the Tertiary almost down to the present. The recent basaltic lavas of the Yukon and of the Koyuk and its environs bear witness to this period. As has already been pointed out some of these lavas are so recent that they overlie the gravels of the Noxapaga basin, whereas others are so much older that they stand at least a hundred feet above the present streams, which have carved their valleys through them.

Many of the lavas flow down the lowland areas of the preexisting topography. In these depressions they were consequently thicker and have therefore been less thoroughly removed by erosion. From the distribution of the residual patches it is therefore possible to reconstruct in a measure the former topography, and it is from this reconstruction that one is able to state that much erosion must have affected the structure produced by the post-Cretaceous deformation before the effusion of the lavas.

While the volcanism was in progress, erosion still continued over much of the area and the highlands were degraded and deposits were formed off the coasts. The erosion, however, did not proceed uniformly, for there were undoubtedly movements of the earth's crust whereby certain parts were uplifted and others depressed. On the whole, however, these movements were gentle, broad, regional uplifts and were not acute mountain-building deformations. Because of uplift movements the streams were at times forced to cut their channels deeper into the bed rock of their valleys, but at other times, because of depression, they found the rock floors too deep and were forced to lay down some of the waste they were transporting, and thus aggrade their courses. Changes of this sort, however, did not exercise any considerable effect on the form of the region except to reduce the relief consistently.

After erosion and deposition had been in progress for a long time a change in the climatic conditions resulted whereby glaciation of the valley type was developed in the highland areas. Apparently this event took place when the sum of the preglacial movements had resulted in the region standing relatively lower than it does now with respect to sea level and grade level. The main result of the period was to scour out the mountain valleys and distribute the waste thus formed beyond the area occupied by the ice. From fossils associated with the deposits formed at this time it seems probable that this occurred in the Pleistocene, which was also the period of maximum glaciation in other parts of the northern hemisphere.

As the vigor of glacial conditions abated, the glaciers receded into the hills and finally disappeared. A long time, however, is required for this process, as is shown by the various moraines in the Pargon Valley and elsewhere in the mountain region. All this time deposits of glacio-fluviatile, fluviatile, and marine origin were being formed in the areas not occupied by the ice where the conditions were favorable. Lava flows may also have occurred at this same time in the areas not occupied by the ice.

With the close of glacial conditions oscillations of the crust similar to those preceding the period of glaciation again become evident. It is not intended to imply that these oscillations ceased during glacial time, but the evidence is so obscured that the movements were not recognized. The general result of these postglacial uplifts has been to raise the region somewhat above the relative position it occupied during the Pleistocene. Apparently, however, the sum of the recent upward movements has not yet equaled the sum of the earlier downward movements, so that the floors of many of the larger streams are still below sea level. The general recent uplift is shown in the rock-walled shallow canyons in which many of the streams flow.

Although the late Tertiary to Recent movements have been described as resulting in certain general conditions, it should be distinctly understood that these movements were such that while depression was taking place in one part of the region uplift may have taken place in another. Hence it appears that deposits at the same elevation above or below sea level are by no means synchronous and may be entirely unrelated in origin. Contemporaneity of the various deposits can only be determined by careful and detailed investigations of the region. Inasmuch as many of the problems of economic importance are connected with the correct correlation of the different deposits, it is necessary that such correlations should be searchingly investigated and not be based on superficial examination or upon apparent similarity of factors known to be variables.

In order to summarize the history of the region as determined the table shown in figure 10 has been prepared. It is at best but a graphic representation of the facts already given, and has the disad-

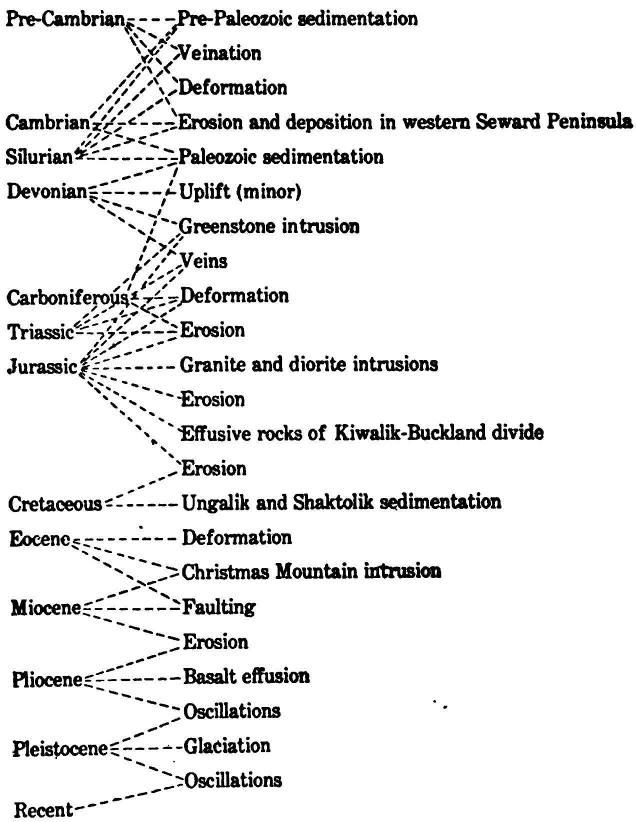

FIGURE 10.—Diagrammatic summary of geologic history of Nulato-Council region.

vantage of giving an appearance of finality to the correlations, some of which the text has shown to be founded on insufficient data; for these reasons it should be regarded as a summary and should not be used independently of the text.

ECONOMIC GEOLOGY.

In the preceding description of the areal geology of the region it has been shown that east of Koyuk River the country is formed of late sedimentary rocks that are little if any metamorphosed, whereas the region to the west of this stream is predominantly one of schists, limestones, and igneous rocks. So far as has been indicated by mining in contiguous areas the metamorphic rocks are those in which deposits of gold may be sought with some promise of success, whereas the unmetamorphosed sedimentary rocks are the ones in which deposits of coal may be found.

PLACERS.

GOLD IN AREAS OF UNMETAMORPHOSED SEDIMENTS.

CONDITIONS OF PLACER FORMATION.

In the unmetamorphosed sedimentary deposits the chances of finding economically important gold deposits are relatively slight, except under local conditions. The Cretaceous and Tertiary deposits, the unmetamorphosed sediments, were formed of material eroded from the earlier rocks and deposited on the sea floor and in estuaries and marshes in essentially the same way that sediments are being deposited at the present day off the coast. Some of the present-day sediments, however, are auriferous, and it might be asked why similar placers should not be found in the older sedimentary deposits. Gold placers should occur in the Nulato-Norton Bay region under conditions similar to those prevailing in the coastal plain at Nome, but there are few places where similar conditions exist.

In order to make clear the different conditions in the two regions it is necessary to point out the salient facts concerning the productive placers of the coastal plain—for instance, those at Nome. A discussion of the character of the surface of the bed rocks is omitted as not important in bringing out the point of the following paragraph.

The known placers are not more than 3 or 4 miles from the old land from which the sediments were derived; the depth of gravel covering the bed rock is seldom over 100 feet; the gravel is as a whole fairly coarse; the rich ground occurs in ancient beaches, which mark concentration by the sea; and the country immediately adjacent to the rich placer is heavily mineralized. Consider the physical and geographic conditions which these facts entail. First, the short distance from the ancient shore line suggests that the gold did not travel far seaward from the place where it might have been formed. This is, of course, a conclusion which would have been reached by anyone accustomed to the action of gold in a sluice box. It might be safely assumed that in general the farther from the source the less gold there would be, other conditions being equal. Evidence of the proximity of the placer deposits to the old land is shown by the second criterion, namely, that the depth of gravel is seldom over 100 feet. This condition, like the preceding, is valuable in establishing the nearness of the gold to its source. The third fact also is of value in further establishing this conclusion, but it is also important as showing that the agencies by which this material was transported were of sufficient strength to permit considerable sorting of the gravel and thus to allow concentration of the particles of gold. As the coastal plain placers are found along old strand lines it follows that in order to make a deposit of economic importance it is necessary to have a marked concentration of once disseminated particles. It is, of course, unnecessary to have this concentration effected by the sea, for streams would do it equally well, as is shown by the numerous creek placers. Perhaps the most important condition which must be fulfilled in order to make a rich placer is the presence of a highly mineralized area in the more or less immediate vicinity. Without this, the other conditions are ineffective.

It has also been pointed out by others that certain physiographic conditions are essential for the production of placers, such as long continued subaerial erosion followed by rapid sweeping off of detritus by revived drainage. As the physiographic history of northwestern Alaska has not yet been worked out in sufficient detail to permit the application of this criterion it can not be critically applied in this discussion.

If now the Nulato-Norton Bay region is considered in the light of the premises enumerated above it at once becomes evident that few of its conditions are analogous to those enumerated. It is true that there are places where the Cretaceous basin is in immediate contact with the old land. This has been proved by the extension of the basal conglomerate from near the Tubutulik northward along the east side of the Buckland-Kiwalik divide. The conglomerate was noted also by Mendenhall[a] on the Kobuk; from which place it swings southeastward. It was recognized, although not correctly correlated, by Schrader on the Koyukuk and by Dall, Collier, and Spurr on the Yukon, and was correctly correlated by Maddren on the Yukon near the Melozitna.

In the belt occupied by the heavy conglomerate the deposits were certainly near enough the shore to permit the formation of placers, but the physical conditions under which this conglomerate was deposited do not seem to have been well suited to the unlocking of gold from bed rock. Instead, the bowlders were riven from sea cliffs and were subjected to trituration rather than to decomposition or disintegration, and whatever gold may have been in the rocks was so abraded before it was deposited that it undoubtedly formed flour gold, which would be much more widely disseminated than flake or shot gold. Furthermore, over a considerable part of the region where the basal conglomerate was seen by the survey party the

[a] Mendenhall, W. C., Reconnaissance from Fort Hamlin to Kotzebue Sound, Alaska: Prof. Paper U. S. Geol. Survey No. 10, 1902, pp. 39–41.

country rock forming the old land shore line against which the sediments were deposited consisted of limestones and igneous rocks. So far as is known from a careful study of the known placer camps farther west, practically no gold is found in the limestones and none is known associated with the granites or other igneous rocks. It will be seen therefore that in the shoreward portion of the metamorphic area the important condition of near-by highly mineralized country rock from which the sediments were derived is wanting. It is believed, therefore, that search for commercial placers, although not entirely out of the question in the conglomerate area, is to be discouraged, unless the field evidence shows the existence of conditions other than those generally encountered in the basal member.

Over the greater part of the Nulato-Norton Bay area it has been shown that the lower member marking proximity to the old shore line is not exposed. It seems probable that through this part of the region the deposits are much higher geologically. From the physical character of the sediments and from the structures observed, such as cross bedding, it seems certain that the higher geological members

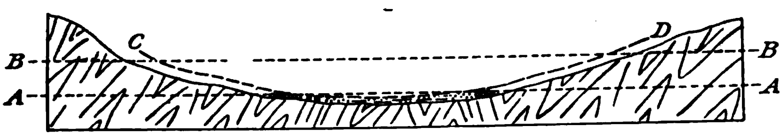

FIGURE 11.—Diagrammatic cross section of the Nulato-Norton Bay region during Cretaceous deposition.

were deposited in relatively shallow water. This fact, however, does not mean that the deposits were near the old land of metamorphic rocks. Figure 11 shows in diagrammatic manner the conditions believed to have prevailed in the Nulato-Norton Bay region. The metamorphic rocks to the left in the figure may be taken to represent the schists of Seward Peninsula, and those to the right the rocks near the Melozitna; the intervening area is the Nulato-Norton Bay region at the beginning of Cretaceous deposition, with sea level indicated by the line AA. At this stage conglomerates were laid down close to the shore of the old land and sandstones and shales toward the center of the basin. Gradually depression took place and continued at such a rate that the surface of the deposits was always within a short distance of sea level. It is evident, therefore, that if this depression continued until the surface of the deposits and the sea level stood at the line BB, no part east of C as far as D had ever been close enough to the metamorphic area, which is assumed to have been the source of mineralization, to have received any notable amount of gold. Consequently, in this part of the region, unless subsequent folding exposed rocks at the surface outside of the part included within the line CD, the probability of finding auriferous deposits is slight, and then only if the old land area from which the sediments were derived was sufficiently mineralized to afford placer gold.

It has been the object in the preceding paragraphs to point out that on the whole the chances of finding gold in the area of unmetamorphosed rocks are slight. From the fact that only under exceptional conditions are valuable deposits likely to be found it seems that the ordinary prospector for gold should be warned against spending much time in the region east of Koyuk River. Not only does this conclusion seem sound from a theoretical standpoint, but it was learned from prospectors on the Inglutalik that they had been from that river eastward to beyond the Gisasa and had not been able to raise a single color of gold.

It is not the purpose of this warning, however, to assert that no gold will be found in the region, for there are three conditions under which deposits may be found. The first of these conditions, already described, is that the unmetamorphosed sediments considered may have been originally deposited at no great distance from the shore of a mineralized area of metamorphic rocks. Such deposits might be found at several places, even in the middle parts of the basin, if subsequent deformation brought the underlying rocks up to the level of erosion. As an example of this condition may be cited the area of metamorphic rocks which appear between Kwik and Koyuk rivers.

The second condition which might permit the formation of valuable gold placers in the Nulato-Norton Bay region is long continued concentration of the material, either by streams or by the ocean. Concentration of this sort may have been effected either during the time the sediments were being deposited or at a much later time. Throughout the period occupied by the deposition of the sands and gravels the region was apparently undergoing almost uninterrupted depression, so that, although there was sorting by water, it was nowhere so effective as it would have been if the region had been one of alternate erosion and deposition, as the coastal plain at Nome has been. In other words, the ancient placers at Nome seem to have been subjected to at least two periods of concentration, whereas the deposits of the other region seem to have undergone but one. Since consolidation, the sandstones and shales of the Cretaceous have been eroded by the streams and a present day concentration is being effected. Some of the reported gold placers in the Yukon basin are probably due to this sorting, but they may have been formed by original sorting before the consolidation of the sediments, for little is known about the deposits.

The third type of locality where search for gold placers or lodes in the area of nonmetamorphic rocks would be warranted is at those places where mineralization has occurred since Cretaceous times.

Such places are, so far as known, closely associated with the areas of intrusive igneous rocks. The effusive rocks or lavas of Tertiary-Recent age do not seem to have brought any valuable minerals, and therefore placers or lodes due to post-Cretaceous mineralization are not to be sought in those areas where only these rocks occur.

Intrusive rocks later than the Cretaceous have been noted at but two places, although a more detailed investigation of the area undoubtedly might result in discovering others. The two places where these later granitic rocks have been examined by the Survey party are at Christmas Mountain, east of Ungalik River and at Bonanza Creek. From reports of prospectors it seems that the placer-bearing gravels of Anvik River may have been derived from a similar area of intrusive granitic rock, although too little is known of the geology of the country to advance this interpretation more than tentatively. Spurr [a] in his summary of the occurrence of gold in southwestern Alaska says:

> The gold in this region is by no means so abundant as it is along the belt of the Yukon geanticline, where the ancient schists with their inclosed quartz veins are found. The mineralization of southwestern Alaska is of a later date and not so intense or widespread. Within the area examined by the writer's party last summer (1898) the Tordrillo Mountains are undoubtedly the chief seat of mineralization, and this appears to be directly dependent upon the fact that these mountains have also been the chief seat of intrusion of igneous rocks.[b]

PLACERS OF THE BONANZA CREEK REGION.

Bonanza Creek is the only stream between the Koyuk and the Yukon where placer mining has been successfully carried on. This creek is only about a mile long, but values have been found almost the entire length of its course, and, from the character of the gold, they seem to be of distinctly local origin. Gold was originally discovered and staked on this creek in 1899 by Thomas Moon and his partner. The absence of water and the boom that the Seward Peninsula placers were having prevented any considerable development for the first few years on Bonanza Creek. After the lower claims had changed hands several times they were bought by the Nelsons, who have since been the most industrious miners there. Other miners have held ground on No. 2 and No. 3 above the Discovery claim, and some work has been done for the last two or three years. It is hard to realize that during the boom days of this camp nearly a hundred men rushed to the creek, and several road houses and three or four saloons were in operation, for now the creek is practically deserted, and only four or five white men are living there.

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[a] Spurr, J. E., Reconnaissance in southwestern Alaska in 1898: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 7, 1900, p. 261.

[b] It is extremely doubtful if the intrusives of the Tordrillo Mountains are post-Cretaceous, as the sedimentary rocks they cut are Jurassic or older.

At first the creek claims were the ones from which the values were obtained. On the lower claim the pay streak was 400 feet wide, but it narrowed upstream and at the northern line of No. 1 above Discovery the width was only about 75 feet. The gravels are typically river wash in form and consist of material from near-by rocks, although some of the pebbles were undoubtedly derived from higher level gravels which were not of local origin. Bed rock is a much shattered black slate or shale, on the whole rather thinly laminated and not so quartzose as the black quartzitic slates of the Paleozoic section. The slates are cut by igneous rocks of the granite family. An exposure of one of the intrusive dikes occurs a short distance north of the cabins at the junction of Bonanza Creek and the Ungalik. Here the dike is apparently about 10 feet wide and shows by its undeformed character that it was injected subsequent to the period of folding and faulting of the slates. It trends obliquely to the slates, having a strike of N. 5° E. and stands vertical. It is heavily iron stained in places. This iron is probably derived from the decomposition of sulphides, some of the unaltered material showing pyrite in microscopic sections.

Above the stream on the northeast side of the valley is a bench on which gravels have been found that are highly auriferous. After the exhaustion of the creek gravels attention was turned to this high-level ground, and satisfactory returns have been obtained from it. Aneroid readings give the elevation of the bench as about 80 feet above Bonanza Creek at the cabins, but some gravels have been found up to an elevation of 150 feet above the stream. The gold on the benches is medium coarse and of a dark reddish color. None of it is black gold. Several nuggets were seen that had small pieces of quartz attached. From the owners it was learned that the largest nugget taken from this creek was worth about $21. The value of the gold is high—that from the lower claim being reported as worth about $19.25 an ounce, and some from higher up on the creek and not from bench ground assaying from $19.05 to $19.15 an ounce.

Concentrates from the bench ground show a good deal of magnetite or black sand. Some of the fragments of this mineral were as much as one-fourth of an inch in length. Together with the magnetite is also ilmenite or the oxide of titanium and iron, which is nonmagnetic. Garnet or the so-called "ruby" sand is practically absent in all parts of the creek. This was to be expected, for none of the rocks in the neighborhood show any such development of this mineral as is the case in the Seward Peninsula placers. Some float pieces of antimony are occasionally found in the gravels of Bonanza Creek.

Bonanza Creek has such a small supply of water that the extraction of the gold from the gravels has been a serious problem. In the early days the separation was accomplished by the use of rockers, and even during the summer of 1909 this method was still in use on some of the creek gravels half a mile or so above the mouth of the stream. The discovery of gold in the high benches called for a supply of water at considerable elevation. Ditches except of such length as to be prohibitive in cost were not feasible, and the experiment of pumping water from Ungalik River was resorted to. Wood cut in the neighborhood of the mines was used for fuel. Although no figures are available as to the cost of the water delivered on the ground, it seems that the fact that this method was pursued until the claims were worked out is sufficient proof that the owners were satisfied with the project.

The method of work was to make cuts at intervals at right angles to the trend of the old channel. In these trenches sluice boxes were placed in such manner that their lower end discharged toward Bonanza Creek. The abrupt cliff that occurs at the edge of the bench deposit offered particularly favorable topography for the discharge of tailings on the lower ground so that the boxes would not become choked, and this was taken advantage of. The water pumped in two lifts was delivered to the nozzles on the bench ground and the gravels and overburden were washed through the sluice boxes. After the gravels had thus been sluiced off, the bed rock was taken up by hand and cleaned. In places three feet of the rather angular blocky slate had to be picked up to recover the pay-values, but over much of the bench ground it was necessary to take up only from 12 to 18 inches.

During 1909 the last of the bench and creek ground nearest the mouth of the creek was exhausted, and the boiler and pump were dismantled and put into condition to be shipped away; the lower claims may now be regarded as worked out. Good bench placer ground, however, continued from the end line of the claim, and the next upstream claim undoubtedly contains valuable deposits. During the early part of 1909 the owner of this ground was engaged in building a small ditch from the upper part of Bonanza Creek to bring water to this bench. The small amount of water available, however, makes it probable that the operations will be much hampered. The bench ground is frozen, and either a strong head of water will be required to break down the gravels or else the owners will be forced to resort to thawing.

On the fourth claim above the mouth of Bonanza Creek little work was accomplished during 1909 and that mainly of a prospecting character. The unusually dry season made this part of the stream practically dry by the middle of July, and the only gold taken out was by means of rockers. At this place specimens of gold in a black graphitic slate were seen. This occurrence suggests that the carbon, which is abundant in the slates, may have been effective in causing the deposition of the gold.

At the mouth of Bonanza Creek some gold has been found in the gravels of Ungalik River. Several rather shallow holes have been put down in the river flats, a few score yards north of the mouth of Bonanza Creek, and good prospects have been reported. On the whole, however, the tenor of the gravels of Ungalik River is low, and, although occasional 5-cent pans have been found, the average indicated is so low that the ground could not be worked without labor-saving devices capable of handling large quantities of gravel at a low cost. The gold is reported to be irregularly distributed; rich pockets separated by intervals of barren ground are to be expected, which condition is not one calculated to encourage the development of large undertakings.

The other placer where post-Cretaceous mineralization apparently associated with igneous intrusions has been reported is at Christmas Mountain. Scores of lode claims have been staked on this mountain, but, with the exception of a little sulphide mineralization, few indications of profitable veins have been disclosed. In spite of the apparent absence of lodes that would warrant extensive development it is believed that there is a disseminated mineralization in the vicinity of this mountain that might justify search for placers in the neighborhood. From the reports of prospectors it was learned that colors of gold had been found in the gravels of many of the streams heading in this mountain and draining either into the Ungalik or the Shaktolik. Several placer claims have been staked on Christmas Creek, which enters the Ungalik 3 to 4 miles north of camp A16, but no mining has been done. It seems probable that the inaccessibility of the region would make it unprofitable to work any but a rather high grade placer at the present time at this place.

It is further reported that stibnite (antimony sulphide) float has been found on the divide between the Shaktolik and the Ungalik, about 4 miles northeast of Bonanza Creek, on the slopes of Christmas Mountain. This mineral was not found at this place by the Survey party. Its presence would indicate that there has been a good deal of mineralization and would show that the sulphide mineralization already noted may have introduced many different minerals.

In the same general region, but not definitely associated with intrusive igneous rocks, are streams that are said to have some auriferous gravels; the geology of these places is too indeterminate at the present time, however, to warrant even a suggestion of the origin of the valuable minerals contained. Garryowen Creek, a tributary of the Inglutalik heading in the Ungalik divide, is reported to yield colors of gold. Negromoon Creek, which joins the Inglutalik from the west upstream from Garryowen, also shows gold-bearing gravels. The values, however, on both these streams are so low that they are of no commercial significance at the present time and can not be worked under existing conditions. No adequate prospecting has been done on any of these streams, and it is therefore impossible to make even an approximation of the tenor of the gravels.

GOLD PLACERS IN AREAS OF METAMORPHIC ROCKS.

DISTRIBUTION.

As the metamorphic rocks are older than the nonmetamorphic rocks they have been subjected, broadly speaking, to at least the same number of periods of mineralization as the latter plus whatever number occurred before the laying down of the Cretaceous sediments. It is, of course, realized that mineralization may be distinctly local and may affect one region and not another, and it is not intended to assert that the richness of a region is necessarily dependent upon the number of periods of mineralization it has undergone, although, according to the law of chances, such a generalization is sound. This view receives corroborative support from the field evidence, for in most of the Seward Peninsula placer regions there were at least two periods of vein formation, during each of which gold lodes were made, whereas in the area of unmetamorphosed sediments only one period has been recognized.

Valuable gold deposits have been mined most extensively in Seward Peninsula where the metamorphic rocks are most abundant, and it is believed that regions underlain by them are the most promising areas in which to prospect for new placers. In general, the richest placer areas are near the contacts between the heavy overlying older limestones and the underlying quartz chlorite schists. So far as known, the intrusive igneous rocks older than the Cretaceous are not auriferous, and neither are the more recent lava flows. Therefore, areas deriving their surficial deposits from such rocks are not likely to afford valuable placers.

Several of the various placer camps located within the area covered by the map of southeastern Seward Peninsula were not visited during 1909. It has been thought desirable, however, to summarize the investigations made during previous years in order to gain a more comprehensive idea of the mineral industry as a whole, rather than to omit districts so important as Council and Bluff simply because they have been already described. Consequently, to complete this part of the report it is necessary to refer to the published reports of Brooks, Moffit, Collier, and others. In the treatment of the gold placers of the areas of metamorphic rocks a geographic order will be adopted. The placer deposits of a single river basin will be treated from the mouth toward the head of the stream. The various river basins tributary to Norton Sound will be described from east to west, beginning with the Koyuk, and then will follow descriptions of the various basins emptying into Kotzebue Sound from Buckland River westward.

KOYUK RIVER BASIN.

In the Koyuk Basin no gold placers are now being mined and commercial mining has been done in but few places in the past. Colors of gold have been found on many of the streams and many attempts at mining have been made in the region, but so far without sufficiently encouraging returns to keep a permanent force on any of the streams.

About a mile west of camp B17, at the mouth of the Koyuk, there is a black limy schist and limestone that occurs east of a lighter-colored schist, the dip of both being practically vertical. On the beach at this place and extending for a considerable distance both east and west are many large angular pieces of quartz float that suggest vein material. Pans of broken-up material from the schists near this place show a number of very small colors of worn placer gold. From a prospector living near the place it was learned that 1-cent pans had been found, but the small returns were not sufficiently encouraging to warrant any considerable expenditures of either time or money.

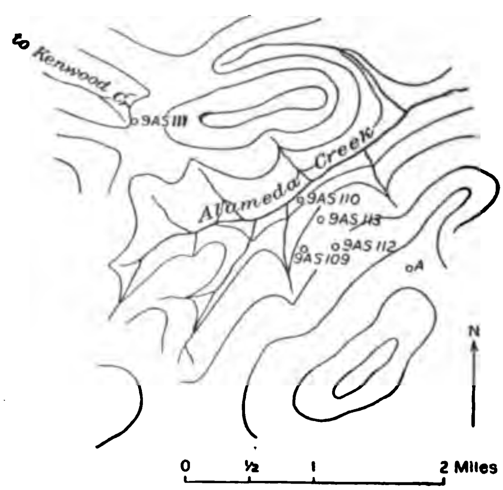

FIGURE 12.—Sketch map of Alameda Creek.

Alameda Creek, a small tributary to the Koyuk from the west, joining the river a short distance below the mouth of East Fork, was visited in the early part of August. Although no active work was in progress the problems that have been raised by earlier prospecting are such as to attract the attention of the geologist. Figure 12 shows the headward portion of this stream with the location of the different prospect holes that have been sunk. The elevations are only approximate, as the weather was so changeable that an aneroid was of no assistance.

At locality 9AS109 south of Alameda Creek a shaft 192 feet deep was sunk all the way through well-rounded, predominantly quartz gravel. The upper part of the gravel is whitish, with black quartzite pebbles and some glassy lava; not many pebbles of the latter material were found. Midway in the shaft the gravels are more yellowish and more iron stained than in the upper part. In the lower part of the hole the fine material is of a greenish-white color but is otherwise similar to that above. On reaching a depth of 192 feet the miners were forced to abandon the shaft, as they encountered a great deal of water. This condition suggests that they were approaching bed rock. This conclusion receives some support from the fact that in the bottom of the shaft pieces of ancient lava, probably the country rock here, became more numerous.

It is reported that in the general gravel section cut by the shaft a few thin sedimentary layers were found that gave fairly good prospects. A pan of the gravel from the dump which was said to have come from near the top of the shaft gave two small colors. Samples from the gravels said to be near the bottom of the shaft showed also minute specks of gold. In the concentrates from the same part of the section there was a good deal of black sand, but garnet was practically absent. A good many pieces of undecomposed sulphides were also recognized in the concentrates. Within 100 feet of the shaft a pan from the surface gravels directly under the grass roots showed several bright colors of gold, some magnetite sand, and ilmenite.

Nearly due east of the last locality and at an elevation about 100 feet higher another shaft has been sunk (locality 9AS112). The depth of the shaft is somewhat over 70 feet and it has not reached bed rock. The material on the dump consisted mainly of well-washed white quartz gravel, with some pebbles of black quartzite and red lava. Twenty-five feet east of this hole and at a slightly higher elevation a shaft had been sunk 45 feet without reaching bed rock. The material on the dump at this shaft was more sandy and the pebbles were smaller than at the shaft at locality 9AS112.

Northward down the slope at locality 9AS113 another shallow shaft has been put down. It was only about 15 to 20 feet deep, and in it no gravel at all was reported.

On a low bench on the south side of Alameda Creek, at an elevation of less than 10 feet above the water, there is a caved shaft (locality 9AS110). This was originally 32 feet deep and reached bed rock, which belonged to the group of ancient igneous rocks. There was a great deal of well-rounded quartz gravel, but as a whole the material on the dump was much darker than at locality 9AS109, and there was a much greater proportion of lava fragments. The prospectors who sunk this shaft reported that the values were found entirely on bed rock and that the lower gravel went about 1 cent to the pan. Upstream from this shaft the present gravels of Alameda Creek are reported to carry no gold, whereas northeast, or downstream, the creek gravels yield about 7 cents to the 10-pan bucket. A mile and a half downstream, however, even this amount of gold disappears and the gravels are barren. From these facts it would appear that the present creek may derive its gold from the earlier channel. It should be remembered, however, that if the values occur mainly on bed rock in this channel the bottom is still below the level of Alameda Creek, and therefore the reconcentration has not affected the richest portion of the old channel.

Directly across the creek and at the same elevation above the stream as locality 9AS110 a shaft 12 feet deep has been sunk to bed rock. The bed rock at this place also was dark, much fractured, fine-grained lava. A pan of gravel from the dump at this place showed an abundance of green lava sand with numerous hornblende crystals. Several well-rounded garnets were also noted.

A mile and a half west of this shaft and on one of the small tributaries of Kenwood Creek some further prospecting has been done to try to locate the northwest continuation of the old channel. At locality 9AS111 there is a shaft 24 feet deep, now badly caved. The material on the dump is nearly all angular, almost completely decomposed rock, which seems to contain some rounded black pebbles. The material is so badly changed that it is impossible to assert definitely whether it represents a recent slightly consolidated gravel or a more ancient sandstone or fine grit. It was claimed by the prospectors that bed rock was reached in this shaft and samples of the material supposed to be from the bottom of the hole showed thin quartz and calcite veins with decomposed material between. Some of the quartz was much slickensided.

Forty-five and sixty-five paces west of locality 9AS111 were two other prospect pits at a slightly lower elevation than the one last described. The western one showed undoubted gravel on the dump, some of the pebbles being 3 to 4 inches in diameter. There were very few white quartz pebbles, the greater number being of black quartzite. There seems to be little room to doubt that this is a portion of the same deposit encountered in the deep shaft at locality 9AS109. It is unfortunate that the depth to bed rock has not been determined at the two places, for it might afford information either as to the direction of the old drainage or as to the amount of deformation since the cutting of the channel.

On the broadly open saddle, 1½ miles southwest of locality 9AS109, quartz gravel is reported to be abundant, and it is believed that this low pass may mark the southern continuation of this channel. On this assumption a party of three or four men was engaged in prospecting during the winter of 1909–10. From a recent letter it seems that little was accomplished at this place during the winter, and although seven holes from 18 to 24 feet deep were sunk their location is not sufficiently explicit to show the relation to the surrounding topography. It was stated, however, that they found but little of the well-rounded wash noted at locality 9AS109. In several of these holes colors of gold were found, but apparently not enough to warrant further prospecting. It should be pointed out, however, that even if this be the old course of the valley it does not follow that the gravels will be commercially valuable, for, as has already been noted, so far as prospected the gravels in the deep hole on Alameda Creek are not sufficiently gold bearing to be mined at the present time.

Not enough facts are yet available for more than a tentative interpretation of the conditions under which the old channel was formed. It is evident from the presence of lava in the gravels of the channel filling that the channel was carved and occupied by a stream later than the effusion of the recent lava. It seems probable that a rearrangement of drainage may have resulted from the extrusion of the tongue of lava which occupied the low country between Koyuk and Buckland rivers and flowed down the present Koyuk Valley below East Fork. This may have resulted in turning the lower part of the Koyuk out of its former course and allowing it to cut its gorge. After the gorge had been eroded, either by change in the relation of the land with respect to sea level or by capturing, the old valley was filled and the stream was so diverted that it took up a course parallel with the tongue of lava that flowed down the Koyuk Valley. It eroded the lava, thus etching out and uncovering its former valley, in which it now flows.

In regard to the origin of the gold found in the old valley gravels there is some question. Alameda Creek is near the area of metamorphic rocks, and the presence of a great number of pebbles of vein quartz in the gravels suggests that they at least have been derived from the quartz stringers in this series. If this vein quartz has been derived from this source there is a strong presumption that the gold has also come from the same place. On the other hand, it should be noted that there are indications that some of the ancient lava is mineralized. A shallow prospect pit has been sunk on a ledge of amygdaloidal trap outcropping on the divide between the Koyuk and Alameda Creek at A, on figure 12. Assays made at Nome of material from this pit are reported to have given as high as $3.72 in gold per ton. The rock shows no macroscopic mineralization, and considerable doubt is felt of the accuracy of this determination.

Kenwood Creek, which enters the Koyuk from the south above East Fork, has been prospected near the head, as already noted, and a little work has been done also on the lower part. Two prospectors, who were reported to have found good prospects at this place several years ago, went to the lower part of Kenwood Creek during the summer of 1909. The low water prevented their getting upstream far enough with their boat and they returned. It is probable, however, that bed rock through the lower part of the creek is deep and difficulty with water will be experienced.

On Willow Creek, which enters the Koyuk from the south above Kenwood Creek, there are signs of former prospecting, but the stream is now deserted. McPherson says that at the time of his visit (1907) location notices were seen, which showed that the prospecting had been done about five years before.

Peace River is one of the northern tributaries of the Koyuk west of East Fork. About 12 miles above the mouth it forks, and near this place some prospecting was done during the winter of 1908. Two shafts were put down on the east bank of the river, but they were so badly caved that only the upper 3 feet or so was visible. This part of the section shows brown, irregularly bedded sands of even texture, having in general a dip toward the west—that is, toward the stream. The material on the dump is fairly well-rounded river wash, consisting almost entirely of igneous rocks with some red, iron-stained gravel of the same nature. The eastern of the two holes was probably not more than 15 feet deep, but the other may have been 25 feet deep. Some material put aside as though it were the pay gravel was a greenish-brown sand.

About 100 yards east of this place and on a slightly higher bench there is another shaft now filled with water. This pit was probably not more than 5 or 10 feet deep. From the material on the dump it appeared that the gravel is not so well rounded and there is much more mud mixed with the sand. The upper 2 or 3 feet, which was the only part visible, instead of consisting of sands as in the western holes, was entirely formed of muck. From prospectors it was learned later in the season that some gold had been found in these holes, but not enough to warrant further exploitation. It was currently reported that one piece of gold found there was worth 4 cents, but this was the largest piece. The presence of gold at this place suggests the possibility of some of the ancient lavas having been more or less mineralized, but the evidence is not sufficiently definite to preclude other sources of origin.

Mendenhall notes that in 1900 Big Bar Creek had been prospected and a mining district established there. He was unable to learn the success of the operations, but the fact that in 1903, when this region was visited by Moffit, no work was in progress and the creek was deserted shows that the gold tenor of the gravels must have been too low to make mining profitable.

A tributary creek farther up stream and heading in the hills near the low pass into Death Valley and the upper part of the Koyuk basin is mentioned by Mendenhall as follows:[a]

Just above the camp of September 5 another tributary enters from the south carrying only schistose pebbles. These, however, are very calcareous. Most of the streams which enter the upper course of the river from the north lie

[a] Mendenhall, W. C., op. cit., p. 213.

without the lava belt, but the schists here have not the aspect of the gold-bearing members. At Cheenik in the fall we met prospectors who had been up the river and reported finding colors all along its course.

Moffit in 1903 reported no mining in this part of the river basin, and no signs of recent work were seen by the party in 1909.

KWIK RIVER BASIN.

No mining was in progress during 1909 on any of the streams in the Kwik River basin, and so far as could be learned little or no prospecting has been done in the past in this area. On the head of Quartz Creek, about 3 or 4 miles east of camp C3, there were some old claim stakes and some sluicing had been done several years ago. McPherson, who visited this region in 1907, noted that he found location notices of about five years previous date on this creek.

TUBUTULIK RIVER BASIN.

During the time that the survey party of 1909 was in the vicinity of the Tubutulik no prospectors were seen and no evidence of any recent mining was observed. Practically the only thing that is known about the mining in the basin is furnished by the report of Mendenhall,[a] in which the following statements are made:

> This stream, while farther from the known productive districts than the Fish, was the object of considerable attention during the season of 1900. The surface gravels of the river bars gave colors quite as heavy as those on Fish River, wherever a pan was washed out—at least as far up as the granite area. We had no reports from the head of this stream and did not have an opportunity to examine it ourselves, but the area drained by it is not particularly promising. Mr. C. C. Alexander and members of his party, who had been prospecting on Chukajak and Vulcan creeks during the fall of 1899 and the summer of 1900, report the finding of coarse gold early in their work on the former stream, but more thorough development did not fulfill the promise of this first find. Reports of favorable prospects here had, however, reached Golofnin Bay and Nome, and a small stampede toward the Tubutulik resulted. When we left the river, late in August, many outfits were reaching the field. Reports toward the end of September did not tend to confirm the earlier accounts of rich strikes there.

It was reported that some mining was done several years ago on the next stream above Lost Creek. According to Mendenhall the name of this creek was Admiral, but the claims were described as on Camp Creek. It seems probable that the two names are applied to the same stream, but which is correct could not be determined. From the character of the bed rock near this stream it would appear that the geology is complex and that the older schists form the lower part of the valleys, so that it is presumed the gold was derived from them. Placer mining on Camp Creek was carried on by means of horse

[a] Mendenhall, W. C., op. cit., p. 212.

scrapers, but the absence of any recent work in the vicinity seemed to show that the returns were not satisfactory. From the strong evidence of glaciation of the valley type in many of the streams heading in the Darby Range and entering the Tubutulik from the west it seems unlikely that any rich placers will be found in that part of the basin. The eastern boundary of the basin in the southern part is formed of the Ungalik conglomerate so that strong mineralization is not to be expected from it. Farther north the eastern part of the Tubutulik divide is formed of the Paleozoic limestones, and these are not promising rocks from which to derive placers. It is felt, therefore, that a large part of this drainage basin is not particularly favorable for commercially important placers.

KWINIUK RIVER BASIN.

Practically the whole of Kwiniuk River and its tributaries flow in valleys carved in the igneous rocks that make up the Darby Range. So far as is known these rocks are but slightly mineralized. Consequently there is but little chance that the detritus worn from these rocks would form valuable placer deposits. In the lower part of the course, where the bed rock is heavily covered by unconsolidated deposits, the character of the country rock is not evident, and the more mineralized schists may occur. If this is the case, there is some possibility, where concentration has been effective, that placers may be discovered. The depths of covering and the question of handling water would make the development of such placers difficult.

FISH RIVER BASIN.

MAIN STREAM.

The main Fish River basin has not been important as a placer district, although the tributaries of the Niukluk, its longest western branch, have produced more gold than those of all the rest of the region. The name of the principal town, Council, will be used to designate this placer region in order to distinguish it from the rest of the Fish River basin. According to Mendenhall[a] Fish River carries gold from its mouth to the northern end of the gorge. Throughout the lower part of the river the colors are very light, but they become heavier in the constricted part of the valley, where the stream crosses the belt of limestones and schists. Opposite the mouth of Anaconda Creek, as the lower part of Pargon River is called, pans taken from the broken rim rock yielded from one-half a cent to 1 cent each. According to the same author prospectors found nothing in the upper flats of Fish River, and so far as reported the streams flowing out of the mountains to the north do not yield colors.

[a] Mendenhall, W. C., op. cit., p. 212.

From the geologic description of the northern and eastern part of the Fish River basin it is seen that the rocks are schists and limestones, which appear to be the same as the rocks in some of the placer regions, except that the schists contain much greater quantities of biotite. Veins are equally abundant in both types, and it is believed that the absence of placers may be explained in part by the valley glaciation that has scoured out the water-sorted deposits from most of the valleys heading in the Bendeleben and Darby mountains. This process has scattered the deposits, which may have existed in the valleys prior to this erosion. Information on the subject is still too meagre to allow a final judgment as to the reason for the absence of placers in this part of the basin, but it is believed that the physical history rather than the lithologic character is responsible for the apparent absence of placers.

COUNCIL REGION.

Placer gold has long been known in the region around Council, for it was reported by members of the Western Union Telegraph Expedition in 1865, and in 1892 John Dexter is said to have notified members of the silver-lead mining company that he had found gold there. It was not until 1896–97, however, that the discovery of Ophir Creek, the richest one in the Council district, was made by Mordant, Melsing, Libby, and Nelson. Although, apparently, gold was found at that time, it was not until the spring of 1898 that the district was organized and active placer mining begun. So valuable have the placers turned out that in 1903 Collier estimated that the gold output up to that year was between $5,000,000 and $6,000,000.[a] Since that time $2,000,000 to $3,000,000 more has been taken out, so that this camp has been second in production to that of Nome.

The productive creeks in this so-called Council region from southeast to west are Fox, Mystery, Melsing, Ophir, Goldbottom, Camp, and Elkhorn creeks. All except Fox Creek are tributaries of the Niukluk, and Fox Creek joins Fish River less than 4 miles below the Niukluk.

Fox Creek has never been a rich creek. The only valuable ground was on a small tributary known as I. X. L. Gulch, and on the main valley at the mouth of this stream. At this place, according to Collier,[b] about 2 ounces of gold were taken from about 4 cubic yards of pay dirt. A little prospecting has been done here in every year since 1906, but the production is practically negligible.

Collier[c] reported that on Mystery Creek, 1 mile from its mouth, $6 to $8 nuggets have been found. Part of the gold was bright and

[a] Collier, A. J., and others, The gold placers of parts of Seward Peninsula, Alaska: Bull. U. S. Geol. Survey No. 328, 1908, p. 236.
[b] Idem, pp. 237–238.
[c] Idem, p. 240.

part was rusty, but all is rough and angular as though derived from near-by sources. On Mud Creek, a small side stream from the west, one claim was operated in 1903. The gold here, according to Collier, is found both in the gravel and to a depth of 3 or 4 feet in crevices of the bed rock. It is very rough, spongy, and somewhat rusty, and is coarse and easily saved. Near the mouth of Mystery Creek a hole 102 feet deep was sunk, but no values were found. In 1907 and for the succeeding two years there has been mining on this creek, but the production was small though the returns were commensurate with the amount of time spent.

Melsing Creek was one of the first creeks on which gold was discovered, and it has been a constant though small producer ever since. According to the 1900 report, 40 men were engaged on the creek. Collier estimates that up to 1904 about $50,000 had been taken from this stream. The auriferous gravels seem to occur only below the mouth of Basin Creek. From this part of the creek the small pieces of gold are reported to be nearly all smooth and bright, whereas the larger ones are rusty. Richest concentration occurs on a clay layer. At the mouth of Basin Creek the gold is found throughout the gravel, but is most abundant on and in bed rock. Collier states that the average yield per man per day in 1903 was about $50.[a] One of the nuggets examined by him from this claim showed a small, square hole filled with hydrous iron oxide, probably the mould of a pyrite crystal associated with the gold.

In 1906 there had been four parties of 3 to 10 men each on Melsing Creek below Basin Creek. In 1907 a steam scraper was built at the mouth of Melsing Creek, but delays in building prevented its running full time. Work still continued near the mouth of Basin Creek and a short distance down stream. During 1908 and 1909 work was continued on about the same scale and at the same places as in the past, and, in addition, during the last-mentioned year, some mining was done on the lower part of Basin Creek. The operations were, however, on a small scale and the production was slight.

Ophir Creek is the most important gold producer in the Council region. By 1903, according to Collier, the entire creek had been prospected, and during that year 1,000 men were at work on the main stream and its tributaries. Gradually the number of men employed has decreased, but this has been due in part to the replacement of hand labor by mining machinery. Some mining was done in 1903 at the mouth of this stream in the Niukluk River flats. These gravels are estimated to carry from 50 cents to $1 a yard in bright, nearly flour, gold. Concentrates show much magnetite and garnet, with smaller quantities of pyrite and ilmenite. This deposit was developed

[a] Idem, p. 242.

by a steam dredge with an estimated capacity of about 3,000 cubic yards per day. Bed rock is rather deep and the difficulty of handling the water makes mining expensive. According to Collier, the gold has been derived not only from Ophir Creek, but also from the other streams.

Farther up Ophir Creek the gold becomes coarser and the values per cubic yard are higher. After a short experiment on the ground near the mouth of Ophir Creek already described the dredge was moved upstream and has been in successful operation ever since. In an account of this dredge recently published by Rickard[a] it is shown that the average cost is 32 cents a yard and the average gold tenor of the gravels worked is 84 cents a yard. The low value per yard is in part due to the fact that some of the ground had been worked before by more primitive methods.

Next upstream on Ophir Creek from the dredge, hydraulic mining has been tried and some good placer has been uncovered. The ground mined is now mainly on a low bench, but in the past the creek gravels have been worked by pick-and-shovel methods with satisfactory results. Still farther upstream and only a short distance below Sweetcake Creek is the Discovery claim. It has been worked for several years but was finally exhausted by the use of hydraulic elevators. The values were in fairly coarse gold of a bright color. This claim was probably the second richest on the entire creek and it is reported that $1,000,000 was taken from it.

Sweetcake Creek was staked in 1898 and was the scene of probably the first successful placer mining in the precinct, it being reported[b] that $36,000 were taken from one claim that year. The only productive claims are on the lower part of this stream; they were notable contributors in the early days of the camp, although since 1903 little gold has been won from them. Some of the gold was angular and showed quartz attached.

Little of value has been found on the main stream for nearly 1 mile above Sweetcake Creek. At this place, however, there is creek and bench ground that has been very rich. Pick-and-shovel methods were used even in the early days and in 1907 an unsuccessful attempt was made to use a dry-land dredge, which was followed by the successful use of a derrick and horse scrapers. The pay streak in the creek was from 100 to 200 feet wide. The bench gravel near this place, according to Collier, was not well sorted.[c] The pay streak is said to run 10 to 15 cents a pan. One nugget worth $3.75 is reported by Collier to have been found here, but nearly all the gold is fine and flaky.

[a] Rickard, T. A., Dredging on Seward Peninsula: Min. and Sci. Press, vol. 97, 1908, pp. 234–240.

[b] Collier, A. J., and others, op. cit., pp. 250–251.

[c] Idem, p. 245.

From this place nearly to the mouth of Dutch Creek the Ophir Creek gravels and benches have yielded probably nearly $750,000 in gold. In the central portion of this part of the valley the presence of limestone bedrock allows a large portion of the water to flow in subterranean channels and it is notable that the quantity of gold in the gravels decreases also. At the mouth of Dutch Creek the richest claim in the whole Ophir Creek basin was located, and, although now exhausted, this claim and the claim next below probably produced nearly a quarter of the gold won in the entire Council region. Much of the gold seems to have been of local origin, as pieces with quartz attached were by no means uncommon. On Dutch Creek little has been done and then only on the lower claims adjacent to Ophir Creek. Values are reported both in the creek and bench gravels.

Above Dutch Creek the values in Ophir Creek suddenly decrease and then gradually increase toward the northwest to within a mile or so of Crooked Creek. All of the claims between these two side streams have been mined to some extent. A mile and a half above Dutch Creek, according to Collier,[a] excavations show from 5 to 14 feet of gold-bearing gravel resting upon broken limestone bedrock, and three-fourths of a mile to the north 6 feet of sand and muck rest upon about 12 feet of gravel of which the upper 2 or 3 feet carry very little gold.

In 1903 the only other work done on Ophir Creek was near the mouth of Crooked Creek. "Here terrace gravels on the left bank were being exploited. The bedrock of the deposit is probably little above the present creek. A section showed 2 or 3 feet of muck overlying 5 or 6 feet of gravel which rested on calcareous schist."[b] No work was in progress during 1906, but near this place during 1908 and 1909 a small dredge was installed and according to local reports was giving satisfaction in handling creek gravels.

Crooked Creek has been one of the richest tributaries of Ophir Creek. Collier noted that in 1903 more men were employed there than on any one of the other side streams. Near the junction of this stream with Ophir Creek the pay streak is about 250 feet wide, but it narrows rapidly upstream. According to Collier,[c] the pay streak is reported to have been about 6 feet thick. The gold tenor of the gravels mined is estimated at $4.50 to the cubic yard. The gold is comparatively coarse and the pieces well rounded. Some are bright and others are iron stained. In the sluice boxes are found heavy concentrates consisting principally of garnet and magnetite, but including some topaz. Above the lower claim the pay streak is, in the main, not more than 20 feet wide and the bedrock is a schistose limestone.

[a] Idem, p. 249.
[b] Collier, A. J., and others, op. cit., p. 250.
[c] Idem, p. 252.

Balm of Gilead Gulch, which enters Crooked Creek from the southwest, had gold "from the surface down, but is richest in the crevices of the limestone. The gold is rough and angular, with sharp corners,"[a] and is undoubtedly of local origin. Albion Gulch contains auriferous gravels throughout its course. In 1907 two camps were established on this stream, and a rich hillside placer was mined by hydraulicking. The difficulty of obtaining an adequate constant supply of water has much hampered developments on both of these gulches.

Above Crooked Creek the valley of Ophir Creek has been prospected, but little actual mining has been done. Near the upper end of the canyon of Ophir Creek there is a little bench gravel, which was being developed at the time Brooks visited the region in 1903. Although this work may have yielded wages, it was not highly remunerative and was soon abandoned. Further prospecting was undertaken here in 1907, but was not successful in locating placer.

From the general distribution of the values in the Ophir Creek gravels it seems evident that many of the rich placers of the stream are formed by the reconcentration of former bench deposits. At other places, however, it seems clear that the richness is due to proximity to local mineralization. Collier notes that a sample taken from the schists adjacent to some quartz stringers near the mouth of Ophir Creek contained some gold and that samples crushed in a hand mortar and panned yielded free gold. On Crooked Creek there "is a mineralized belt 12 feet wide, which strikes northwest. In this impregnated zone vein quartz is associated with pyrite. It is reported to assay as high as $8 to the ton."[b] Near this place on the divide, between Gold Bottom and Crooked creeks, there is a lode which seems to be similar to the one previously noted; it is significant as pointing to the origin of some, at least, of the Crooked Creek gold, which is very sharp and angular and in many instances has quartz attached. None of these mineralized veins have been mined, and it is doubtful whether the diffused character of the mineralization would permit economic treatment. The absence of valuable placer in the upper part of Ophir Creek, beyond the canyon, strongly suggests that the gold was not derived from the biotite schists that occur in the Bendeleben Mountains.

Farther up the Niukluk is Camp Creek. Mining on this stream was described by Collier[c] as follows:

Camp Creek flows into the Niukluk from the south about a mile below Gold Bottom Creek. Several claims were worked on this creek in 1904. The auriferous gravel is from 50 to 100 feet wide and about 3 feet thick, with an over-

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[a] Idem, p. 254.
[b] Collier, A. J., and others, op. cit., p. 252.
[c] Idem, p. 256.

burden of about 3 feet, and is said to carry from 75 cents to $1 a cubic yard. Most of the mining was done by the shoveling-in process, but one claim was hydraulicked.

Only a little desultory work has been done on this stream within the last two or three years.

The next gold-producing tributary of the Niukluk from the north above Ophir Creek is Goldbottom Creek, with its tributary, Warm Creek. Mining began on Warm Creek in 1900 and up to 1903 the basin is estimated to have produced about $100,000. "Most of the gold is rough and iron stained, and some of it is almost black. One nugget, worth $45.10, at $16 an ounce, was found in 1902; and one worth $12.33 in 1903. The concentrates contain ilmenite, scheelite, magnetite, garnet, and some hematite and rutile."[a] Mining has been confined to the portion of the stream near the junction of Warm and Goldbottom Creeks, but colors of gold have been reported from many parts of the basin. During 1906 there was a little mining, but since then practically nothing was done until 1909, when two dredges were erected in the lower part of the valley. It was so late before the dredges were completed that their production for 1909 was slight. Mineralization on a small scale is recognized at many places, and a short distance upstream a vein on which some development work has been done was found at the contact of schist and limestone. "Near the mouth of the creek are two quartz veins, one about 3 feet wide and the other about 1 foot wide, striking N. 30° E. and standing nearly vertical."[b] As the pebbles in the placers all seem to be of local origin, it is probable that the gold is also derived from veins within the basin.

On Elkhorn Creek mining began in 1900 and was reported upon by Richardson[c] as follows:

Near the mouth of the creek 2½ feet of gravel overlie 6 inches of clay and disintegrated bed rock. It is reported by miners that the pay streak is in patches and that the average yield of pans is 5 cents. The bench near the mouth gives colors, but has not been developed. The bed rock is mica schist, interbedded with limestone, and the strike is at right angles to the course of the stream, with almost vertical dips, giving favorable conditions for the concentration of gold. The gold is medium coarse and bright yellow in color. Some very coarse gold has been found stained with iron. The average assay shows its value to be $19.12 an ounce. Quartz is often found attached to the placer gold, and one nugget was attached to a piece of mica schist. This goes to show that it is of local origin. One nugget worth $55 has been found, and several worth from $12 to $16.

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[a] Idem, p. 256.

[b] Idem, p. 255.

[c] Brooks, A. H., and others, Reconnaissances in the Cape Nome and Norton Bay regions, Alaska, in 1900, a special publication of the U. S. Geol. Survey, 1901.

In 1903 this stream was visited by Collier,[a] who reported as follows concerning mining developments:

Since 1900 the placers for about half a mile have been entirely exhausted, but farther up the creek work is still (1903) in progress both in the creek bed and on the benches. It is estimated that the total production of the creek up to date (1903) has been from $110,000 to $120,000.

After 1903 very little work was done on this stream, and when it was visited in 1906 it was practically abandoned and since that time mining operations have not been resumed.

BLUFF REGION.

The region around Bluff has not been visited by Survey geologists since 1906, and the following descriptions are taken from Brooks's report of his visit at that time.[b] In order to condense the account certain parts have been left out and the arrangement has been changed. To connect the retained portions words, phrases, and sentences have been introduced. So many changes have been made that quotation marks have been omitted. Gold is said to have been found at Daniels Creek in September, 1899, by William Hunter and Frank Walker. Beach placer was soon after located and within less than six months $600,000 had been taken from a strip of land less than 1,000 feet long. Meanwhile, the two lowest claims on Daniels Creek were opened and in 1900 yielded probably $200,000 in gold. Most of the production of 1901-2 came from Discovery Claim, at the mouth of Daniels Creek. Meanwhile gold had been found on Eldorado and Ryan creeks and on Swede Gulch. In 1902 a strong company was organized and has ever since been in practical control of the important placer ground. Figure 13 shows graphically many of the more important features of the Daniels Creek placers.

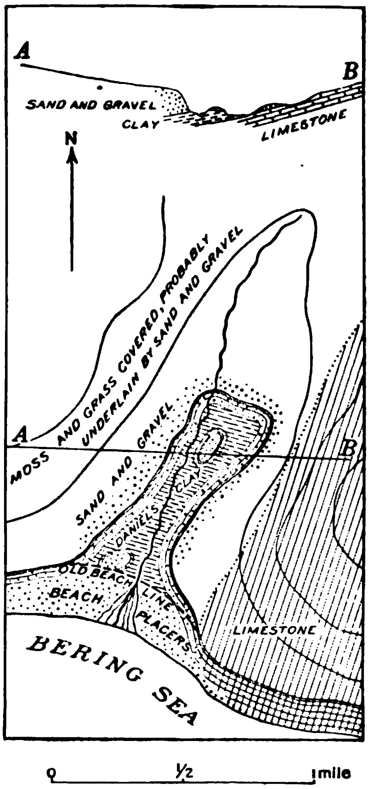

FIGURE 13.—Sketch map and section of Daniels Creek placers.

The placers are of two types, beach placers and creek placers, the former consisting of ancient and recent beaches. The alluvial mate-

[a] Collier, A. J., and others, op. cit., p. 257.

[b] Brooks, A. H., The Bluff region (in The gold placers of parts of Seward Peninsula, Alaska): Bull. U. S. Geol. Survey No. 328, 1908, pp. 283-293.

rial of the creeks is of two general types, that in which clay predominates and that which is chiefly sand. In many places no structure can be made out in the clays; the bedding of the sands and gravels is of the greatest irregularity, locally changing its character every few feet. The indications are very strong that the layers of clay, which in general lie near the bottom of the deposit, are formed almost in place, whereas the sands and gravels appear to have been laid down in swiftly running water. Near the head of the creek the surficial deposits consist chiefly of clay, but near its mouth sands and gravels predominate.

Little can be said of the distribution of pay gravels. The managers of the hydraulic mine report that in general the clay carries higher values than the sand and gravel. This is very significant, for it appears to be established that the sand and gravel have been far more concentrated than the clay. It would indicate a large gold tenor for the rock from which the clay has been derived. In any event there can be no question that the gold is very near its bed-rock source, which appears to be at the contact of mica schist and limestone.

From an examination of the Daniels Creek placers several facts are evident—first, the source of the gold is entirely local; second, where it is richest, as in the red-clay deposits, there appears to have been little sorting action by water; third, the gold is so intimately associated with mica schist débris that most probably the schist has a close connection with its origin. It is evident that the stream gradients must have been low during the period of the formation of the clay. The area was probably exposed for a long time to the agencies of weathering and an irregularly pitted land surface was produced. An uplift followed, as a result of which the carrying power of the streams was increased and the deposits of sand and gravel were laid down. At Daniels Creek this uplift gave the former level a slight tilt to the west, as is shown by the bedding of the gravels. The elevated beach deposit appears to have been formed prior to this uplift, but it would require a very detailed survey to establish this fact. The presence of gold at a depth of 60 feet near the mouth of Daniels Creek reported in 1907 may indicate either a deep zone of weathering or a buried ancient beach line. A subsequent uplift, which probably did not exceed 8 feet at the coast, exposed this older beach in part to wave action and this led to reconcentration of the gold in the gravels of the present beach.

The other creeks of the district besides Daniels Creek have been but little developed, for none of them carry a sluice head of water except early in the spring or during heavy rains. Eventually, however, they will all be hydraulicked with water from the Topkok ditch. Sluicing has been done on about half a dozen claims on Eldorado Creek, and some work has been done on Ryan and Little Anvil creeks. So far as the scanty exposures show, the mode of occurrence of the gold on these streams is similar to that of Daniels Creek, but the deposits are probably not so rich and the auriferous gravels not so extensive.

BUCKLAND RIVER BASIN.

The only stream tributary to Buckland River, on which gold placer has been found, is Bear Creek, which heads in the ancient lava hills that form the western margin of the basin. The first claims recorded on this stream were located by R. S. Hoxie, L. Tendness, and A. Barr, in August, 1901. During 1903, according to Moffit,[a] about 40 men were at work on Bear Creek and its tributaries, Sheridan and Cub creeks, but as only about $10,000 in gold was won from this basin during that year it is evident that the work was not very profitable. Figure 14 shows the location of the principal places where auriferous gravels have been found on this creek.

FIGURE 14.—Map showing location of placer camps on Bear Creek.

Mica schist is said not to be found in this creek, although mica does appear in the sands and gravels, which are composed largely of eruptive material, and on some of the bench claims reach a thickness of 20 feet, with several feet of muck overlying. In places on the creek a considerable quantity of a heavy red cherty rock remains in the boxes with the gold and is a source of some annoyance to the miner. This is especially true on Cub Creek. On Sheridan and Bear creeks the gold is mostly on bed rock, differing in this respect from that on Cub Creek, where it is found throughout the whole thickness of the 2 feet of stream gravel; on the other hand, gold from Bear and Cub creeks is light and flaky, while that from Sheridan is heavy. All the gold is bright yellow in color, assaying $19.20 to the ounce. A little "white iron" pyrite is present and also an abundance of black sand, which is entirely removed by the magnet.[b]

From 1903 to 1907 a little desultory prospecting and mining was done, but during the latter year the building of a ditch along the west slope of the valley revived interest in the region. The small precipitation of 1908, however, prevented any extensive use of the new

[a] Moffit, F. H., The Fairhaven gold placers, Seward Peninsula, Alaska: Bull. U. S. Geol. Survey No. 247, 1905, p. 64.

[b] Moffit, F. H., op. cit., p. 64.

ditch, and in 1909 there was no evidence that productive mining was in progress.

In spite of the small production of gold, this region is of interest as indictaing that the placer has been derived from the ancient lavas that form the Buckland and Kewalik divide. It will be remembered that this source of origin was suggested as a possibility for the placers on Alameda Creek in the Koyuk basin, which is on the southern extension of this lava series. It should be pointed out, however, that although a little local mineralization may have affected this group of rocks here and there, so far as can be foretold by present indications, there is slight chance of finding any considerable extent of rich placer on those streams where the ancient lavas form the country rock. In other words, it is believed that only "one man camps" will be established on streams deriving their gravels from areas of ancient lavas.

KIWALIK RIVER BASIN.

The main production of Kiwalik River comes from Candle Creek and its tributaries. As the larger part of this stream lies outside of the area represented on the map accompanying this report and as the region was not visited in 1909 by the geologists of the Survey party it is desirable to omit any detailed description of the placers. As complete descriptions as the facts in hand warranted have already been published by the Survey.[a] From these reports it will be learned that the production from Candle Creek, on which gold was discovered in 1901, has amounted to about $2,500,000 in gold. During the first years of the camp most of the values came from the creek gravels, but afterward high-level deposits were found which seem to be of a type intermediate petween bench and hillside placers. As these deposits are in places deep, mining has been carried on in winter as well as in summer. According to Moffit:[b]

> The gold is usually flattened and black so that when cleaning out the boxes miners are often seen biting a nugget to make sure that it is gold and not one of the iron stones. Quartz is at times embedded in the larger nuggets and gold is observed now and then in the form of fine veinlets through the iron stones. One nugget weighing $62.10 and a second weighing $36 have been taken from the creek.
>
> Black sand is unknown in the clean ups; pyrite and a few small pieces of rutile which occasionally have been mistaken by the miners for tin ore are the heavy minerals associated with the gold; it is not considered a favorable sign when the iron stones fail.

So far as is known all of the material in the Candle Creek placers is of local origin, although the source of the gold in bed rock has not been determined.

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[a] Moffit, F. H., The Fairhaven gold placers, Seward Peninsula, Alaska: Bull. U. S. Geol. Survey No. 247, 1905.

Henshaw, F. F., Mining in the Fairhaven precinct: Bull U. S. Geol. Survey No. 379, 1909, pp. 364–369.

[b] Moffit, F. H., op. cit., p. 62.

During the early development of this region considerable difficulty was experienced owing to the lack of a sufficient supply of water for mining. This deficiency was met in part by the construction of short ditches within the Candle Creek basin, but as the supply was still inadequate a ditch over 33 miles in length was built in 1907 along the west band of Kiwalik River from the mouth of Glacier Creek to the mouth of Candle Creek. This ditch has a capacity of 20 to 30 second-feet and the height of the lower end above Kiwalik River at that point is about 250 feet. Henshaw[a] in the report already mentioned suggests that the most practical method of obtaining a larger water supply is by pumping from Kiwalik River. Power for such an enterprise might be derived either by using Chicago Creek coal as fuel or by the transformation of water power below Imuruk Lake into electricity.

SUMMARY.

From the distribution of the areas where placers of economic importance have been mined certain facts of value in assisting further prospecting may be learned. Some of the more evident conclusions are as follows: The Cretaceous areas are not promising placer regions and neither are those places promising that derive their deposits mainly from Cretaceous rocks, as, for instance, the marine deposits on the east shore of Norton Bay; no placers of other than distinctly local importance occur in regions deriving their gravels from the pre-Cretaceous igneous rocks; no placers at all have been found in the gravels derived solely from the recent effusive rocks; no gravel deposits derived entirely from the limestones of Paleozoic age contain gold in workable quantities; local placers may occur near the post-Cretaceous intrusions; the most extensive placers occur in the areas of metamorphic sedimentary schists, especially near their contact with the heavy limestones; gold placers are usually found where concentration of gravel derived from the Paleozoic black quartzite has occurred. These general conditions are modified by local conditions; thus in places where concentration has been strong richer deposits are to be expected than in places where less sorting has occurred. From this fact it follows that the glaciated areas hold less promise of placer deposits than the unglaciated areas.

LODE PROSPECTS.

Although, as has been shown, placer gold has been found on many of the streams in the area of metamorphic rocks, no veins sufficiently rich to allow lode mining have been discovered. This is probably in part due to the absence of adequate prospecting. Quartz veins

[a] Henshaw, F. F., op. cit., p. 368.

containing gold have been found at many places and at a few places pits have been sunk; copper sulphides have also been found; and silver-bearing galena has been known almost since the first white men visited the region.

GOLD LODE PROSPECTS.

In order to give an idea of the places where auriferous veins have been exploited the following notes may be of service.

A sample taken from the schists adjacent to some quartz stringers near the mouth of Ophir Creek contained gold in such quantities that when crushed in a hand mortar and panned free gold was obtained. On Crooked Creek, a tributary of Ophir Creek, there "is a mineralized belt 12 feet wide which strikes northwest. In this impregnated zone vein quartz is associated with pyrite. It is reported to assay as high as $8 to the ton."[a] Near this place, on the divide between Goldbottom and Crooked creeks, is a gold-bearing vein which seems to be a continuation of this lead. Mineralization on a small scale has been recognized at several places on Goldbottom and Warm creeks, and a short distance from the mouth of Warm Creek a vein, on which some development work had been done, was found at the contact of schist and limestone. "Near the mouth of the creek [Warm Creek] are two quartz veins, one about 3 feet wide and the other about 1 foot wide, striking N. 30° E."[b]

No productive lodes have so far been found in the Bluff region. Brooks says:[c]

> So far as observed, the schists appear to be mineralized only near their contacts with the limestones. At these places quartz veins cutting the foliation of the schists are not uncommon. The individual veins appear to be of small extent, but at some localities a stockwork forms a considerable mass of low-grade ore. The ores appear to be chiefly iron pyrite with some chalcopyrite and arsenopyrite. * * *
>
> An impregnated zone is well exposed along the sea cliff about three-fourths of a mile east of the mouth of Daniels Creek. * * * At this locality a belt of mica schist about 60 feet wide is more or less impregnated by pyrite-bearing quartz stringers. The belt, including some irregular limestone masses, is bounded by graphitic limestone walls which dip away from the schists and form a small anticline much broken by faults. * * * At the west contact a band of schist 20 feet in cross section lies between one of the included limestone masses and the country rock. In this band the mineralization is more intense than in the rest of the schist. Here a series of gash veins, the largest of which is 18 inches in width, cut the foliation of the schist. [See fig. 15.] A mass of crushed material or gouge forms the hanging wall of this deposit and along this zone, which has been a plane of movement, the quartz veins are cut off abruptly. Stringers of quartz do, however, occur in the limestone on both sides of the schist. The ore appears to be chiefly iron pyrite and mispickel, with some chalcopyrite; the gangue is mostly quartz, with some calcite.

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[a] Collier, A. J., and others, op. cit., p. 252.
[b] Idem, p. 255.
[c] Brooks, A. H., op. cit., pp. 285–292.

Although this mineralized zone was known for several years not much active exploitation was undertaken until 1907. At one claim a shaft 50 feet deep was sunk and a short drift about 15 feet in length was turned off. On the adjoining claim the zone of mineralization is so wide that two shafts, one on the hanging wall and one on the foot wall, have been sunk. One of these is reported to be 100 feet deep; the other is slightly less than half that depth. On the next claim, also, two shafts have been sunk to a depth of approximately 50 feet. Two shorter shafts have been put down on the next claim, and one shaft about 75 feet deep has been sunk near the end line of the next claim beyond. In 1907 the ore from these properties was crushed in an arrastra which was operated by a horse; it was intended to erect a stamp mill later. The developments at this place, however, have not been ascertained for the last two years.

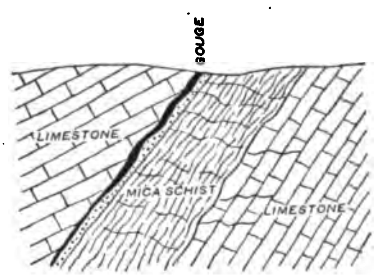

FIGURE 15.—Diagrammatic section of impregnated zones, Bluff region.

According to Brooks, in 1906 a lode 3 miles east of Bluff had been developed to some extent.[a] It was located near the shore, and was said to be 14 feet wide and to yield as much as $30 in gold to the ton. The ore is reported to be iron pyrite and mispickel. A few tons have been sacked and prepared for shipment but practically nothing is known about the mode of occurrence.

A small amount of prospecting has been done near the head of Walla Walla Creek somewhat east of the contact of the igneous rocks and the black quartzitic slates. Although rich specimens are said to have been found here, a careful examination of the rock on the dump failed to disclose enough mineralization to encourage further prospecting. A small amount of limonite staining the joints and fracture planes of the rocks was observed, but there is no vein or distinct lead. Developments at this place consist of an open cut about 25 feet long and a crosscut adit, started about 500 feet away and down the hillside, which has gone in 38 paces (about 100 feet), all the way through barren rock. An analysis of rock from this open cut by Peter Esch, of Nome, gave a trace of gold.

As placer gold is derived from veins, it is certain that auriferous veins must occur widely throughout the area. Whether such veins can be economically mined is a question which can be decided only by more active development. It is probable that if auriferous veins are

[a] Brooks, A. H., op. cit., p. 292.

exploited in the future the mining problems involved will fall within commercial rather than geologic boundaries.

SILVER-LEAD DEPOSIT.

Within the area of metamorphic rocks of southeastern Seward Peninsula one deposit of argentiferous galena has been of some economic value. This lode, staked in 1881, was probably the second one discovered in the entire territory of Alaska. Although the claims were not recorded until July, 1881, galena had been known for a year or more before, and Petrof, in the census report for 1880, mentions that silver-lead ore had been found in the vicinity of Golofnin Bay. The developments at this place have been carried on at a single group of claims located on a low limestone-schist hill on the western flanks of the Darby Range. As has already been stated, the claims were located in 1881. In 1882 a company was formed which in 1883 was absorbed by the Omilak Gold and Silver Mining Company, which continued to hold the ground until 1898, when the Russian-American Mining Exploration Company took the properties. This transfer was one of name rather than of personnel. The claims were patented in 1894.

The geology in the vicinity of the mine is so complex that without more detailed study than was made in 1909 the stratigraphy is not determinable. East of the mine, toward the head of Omilak Creek, is a large area of white crystalline limestone, which, in the main, appears to dip westward at high angles. This is succeeded farther west by schistose rocks containing much biotite and quartz and some graphite. Still farther west, in the immediate neighborhood of the mine, the distribution of the various rocks is as shown in figure 6 (p. 64). Although from this map it appears that the dip is in general to the west, the evidence on the ground shows that the rocks are much deformed, and appressed folds, such as are shown in Plate XIII, A (p. 90), have been recognized. This fold, which pitches steeply toward the west, is shown at A on figure 6 (p. 90). It is evident that with such an amount of folding this structure is by no means so simple as appears at first sight, and even the determination of bedding is often impossible. It is believed, though it has not been definitely proved, that the schists represent younger or overlying rocks.

In addition to the dark biotite schist and the limestones there is an area of slightly sheared igneous rock similar to the greenstones of the more western part of Seward Peninsula. Although the exposures were not sufficiently clear to preclude other interpretations, it seems probable that these greenstones intrude the limestones. Owing to the amount of deformation and consequent metamorphism it is probable that some of the greenstones are included in the areas mapped as schist. The fact that the greenstone is more easily recognizable in the midst of the limestone may be due to the protection given it by that rock, which is more easily deformed than the schist, whose resistance to dynamic metamorphism is more nearly equal to that of the igneous rocks.

According to Mendenhall the ore occurs near the contact of this intrusive and the limestone.[a] From the study of the region in 1909 this conclusion could not be verified as the shaft was inaccessible and the only mineralization seen was in the midst of the limestone. In the absence, however, of ore-bearing minerals in the greenstone it seems doubtful whether the galena could have been introduced at the time of the intrusion. Furthermore, the well crystallized character of the ore suggests that its deposition was later than the deformation of the region, whereas the greenstone was earlier.

Two kinds of ore minerals are found in this deposit—argentiferous galena and stibnite. So far no interrelation between the two has been shown, but it is believed that both were introduced at essentially the same time. It should be noted that the deposits containing the galena seem to be topographically above those with stibnite.

From the reports of others—as it was not possible to see the underground workings personally—it was learned that "no continuous vein of galena ore existed, the ore being found only in irregular and disconnected pockets."[b] None of the pockets were of large size and the better ones occurred entirely within the limestone. Some of the ore was thickly covered with products of oxidation, mostly lead carbonate.

About 400 paces south of the galena shaft there are a shaft and an incline which were used to explore the stibnite leads. The limestone is much fractured and the ore occurs in thin streaks in the shattered zone. None of the veins seen by the writers are of sufficient size to warrant mining. The stibnite is well crystallized, the thicker stringers apparently occupying fault planes and sending small offshoots into the limestone, which, near the ore, is abnormally granular and sugary.

Considering the number of years the ground has been held and the large expenditures incurred, the amount of development work is astonishingly small. A shaft 180 feet deep has been sunk near the eastern margin of the limestone on top of the hill, and two short drifts have been turned off in the search for ore pockets. The upper part of the shaft is in limestone, but the lower is in schist, as the contact dips toward the west. The shaft is well timbered and is fairly dry. Hoisting is done by power, a bucket not running on guides

[a] Mendenhall, W. C., op. cit., p. 214.
[b] Idem, pp. 213–214.

being used. Electric lights are used around the shaft house and underground. Two outfits for drilling have been used, one an air compressor and air drills and the other an electric drill plant. Electricity for these uses is furnished by a coal-oil engine located near the main bunk house on Omilak Creek.

At 200 to 300 feet, vertically, above Omilak Creek an adit has been started to intersect the shaft in depth and thus obviate the necessity of hoisting the rock to the top of the hill and then taking it down again for shipment. The length of the adit is 187 paces, or, approximately, 500 feet; this distance was in massive white limestone somewhat shattered, but nowhere showing mineralization.

In addition to the equipment directly at the mine there are bunk and store houses at Cheenik, on Fish River, and also half a mile or so below the mine on Omilak Creek. At the latter place are a repair shop, electric plant, assay laboratory, electric sawmill, stable, and the other equipment usually found only at large producing mines. The company also owns a large river steamer originally built for freighting the mine supplies up the river, but it has never been used.

The production of the mine is not definitely known, but it has probably not been more than 400 nor less than 300 tons. A part of this was obtained from the various pockets below ground, but a considerable amount is understood to have come from hand picking the float found on the hillside. The following tables show the returns from assays of the ore as shipped. It should be noted that owing to the high transportation charges the ore was carefully hand picked and in some cases washed before shipping.

Returns from assays of ore as shipped from Omilak mine.

	Weight (pounds).	Gold (value per ton).	Silver (value per ton).	Lead (pounds per ton).	Lead (value per ton).	Total value per ton.
1	4,230	....	137.29	1,538	61.52	198.81
2	545	2.07	106.62	1,320	52.80	161.49
3	130,000	3.09	98.72	1,128	45.12	146.93
4	68,078	....	104.00	1,300	52.00	156.00
5	12,167	2.07	125.19	1,440	57.60	184.86
6	82,100	....	132.95	1,494	59.76	192.71
7	86,885	7.43	49.60	502	20.08	77.11
8	27,787	1.54	41.40	606	24.24	67.18
9	13,606	1.54	38.10	566	22.64	62.28
10	2,675	1.03	54.93	770	30.80	86.76
11	6,569	2.07	46.46	890	35.60	84.13
12	164	7.53	65.54	816	32.64	105.71
13	595	2.07	71.15	980	39.20	112.42
14	380	2.07	86.86	966	38.64	127.57
15	26,175	2.07	120.33	1,222	48.88	171.28

1 to 6 inclusive, solid ore from Omilak mine, tons of 2,000 lbs.; 7 to 14, inclusive, carbonate ores from Omilak mine; 15, carbonate ore concentrated by washing in sluice boxes.

Unfortunately, in these assays the data are not sufficient to determine the percentage of any of the constituents except the lead, and therefore the following assays, less complete in certain other ways, are given also:

Silver and lead in ore from Omilak mine.

	Silver (ounces per ton).	Lead (per cent).
1	173.00	75.0
2	141.00	80.7
3	158.00	78.0
4	153.70	82.0
5	162.97	78.5
6	149.16	73.0
7	142 20	74.7
8	94.30	55.9
9	60.7	10.27

Assays 1–2 by Herford Copper Works, Swansea, England; 3 by Pennsylvania Lead Company, Pittsburg, Pa.; 4–6 by W. P. Miller, San Francisco; 7 by T. Price, San Francisco; 8–9 reported by W. C. Mendenhall, op. cit., p. 214; 8 yellow carbonate ore; 9 red carbonate ore.

Assays and relative weights of part of the different ores shipped by the Omilak mine in 1889, with the price paid in open market for the same are given in the following table:

Assays and weights of ore shipped by Omilak mine in 1889.

Commercial name.	Weight (pounds).	Gold (ounces per ton).	Silver (ounces per ton).	Lead (per cent).	Price received per ton.
Red carbonate	380	0.1	92.9	48.3	$93.00
Gray carbonate	595	.1	76.1	49.0	81.00
Yellow carbonate	6,569	.1	49.7	44.5	57.00
Argentiferous galena	82,100	....	142.2	74.7	154.00

It is evident that the ore is high in silver and also usually carries a small quantity of gold. Its metallurgical treatment is simple and the ore is especially valuable to mix with other more refractory ores. The absence of fuel at a reasonable price prevents treatment near the mine and the high charges for transportation restrict shipments to ores of the higher grade.

From the foregoing descriptions certain facts are evident, which may be summarized as follows: The claims have been inadequately prospected and large expenditures have been made, apparently without disclosing a workable vein; the ore found is of excellent quality, but the quantity, so far as could be determined by the writers, is not sufficient to warrant extensive developments. The most promising area to prospect is in the limestone near its contact with the schists, but the deposits likely to be found will probably be pockets not easily adaptable to cheap mining methods and not capable of affording a large, constant amount of ore.

COPPER PROSPECTS.

Attempts have been made to develop copper leads at three places within the Nulato-Council region, but so far the results have not been encouraging, and the general absence of sulphide mineralization throughout Seward Peninsula leads one to doubt whether commercially important deposits of copper will be found. Furthermore, the necessary treatment and refining that copper must undergo before manufacture makes this metal difficult to handle in a country where high wages, high cost of supplies, and absence of transportation facilities exist. It seems likely, therefore, that until one or all of these factors are canceled or reduced, copper mining can be successfully carried on only where the deposit is exceptionally rich. No such places are at present known in Seward Peninsula.

Several shallow prospect pits were sunk in 1906–7 in the hills near Timber Creek in the Tubutulik divide, on copper-stained greenstones, near their contact with limestone. A large outfit was shipped in and extensive plans formulated, but the mineralization was not sufficient to warrant development, and after a little desultory prospecting the ground was abandoned. Specimens of the ore from this claim were assayed and, according to the owners, yielded from 17 to 70 ounces of silver to the ton and from a few cents to $1 a ton in gold as well as copper. From the high copper content reported in these assays, it is evident that the sample for assay was carefully hand-picked. From a personal examination of specimens from this ground it appeared to the writers that the copper occurred almost exclusively in the form of malachite, the green carbonate of copper, and sulphides or other original minerals were practically absent. On account of the secondary character of the ore, it is difficult to ascertain the time or mode of origin of the copper mineralization. The observed facts show that the carbonate occupies fractures and joints in the greenstone, but this does not preclude its having been derived from the leaching of copper minerals originally present in the greenstone. So far as could be determined, the copper mineralization at this place is distinctly local and in such insignificant quantity as to discourage further investigation.

On the east coast of the Darby Peninsula, about 3 miles north of Carson Creek, a little copper mineralization was observed. A small amount of exploration by means of a short, open cut had been made, but no work was in progress at the time of the visit in 1909. The copper occurs mainly in the form of the carbonate, but there is also a little chalcocite present. This ore does not occur in a vein, but seems to be a replacement of parts of the schist, so that its distribution is irregular and discontinuous. Some is also found in the joint planes, as though it had been introduced later than the deformation of the country rock. There is a large amount of slickensiding on the rocks, showing that faulting has occurred, and it is by no means improbable that the shattering effected by these movements may have produced a more or less pervious zone, which allowed easy penetration for mineralizing solutions. The amount of mineralization is, however, slight, and there seems to be no reason for believing that a commercially workable deposit will be found at this place.

A short distance farther south is an outcrop of a nearly pure white limestone, which, though slightly sheared, is in places much brecciated. A short tunnel has been driven in on this brecciated band. Apparently some surface stains had tempted exploitation, but as the work progressed and no vein or other mineralization was found the search was abandoned. From the present condition of the tunnel and the surrounding country rock one fails to understand why mining was ever contemplated at this place.

The only other place where copper prospecting has been undertaken within the Nulato-Council region is in the Bendeleben Mountains on the divide between Kingsland and Nugget creeks. These streams are tributaries of the Niukluk from the east about 4 miles south of the Birch Creek-Niukluk divide. Prospecting in this region has been carried on for five to eight years, but no shipment of ore has been made and no considerable body has been exposed. The ore occurs near the contact of a limestone and schist in a region much faulted and intruded by small granite dikes. The ore is low grade and consists mainly of chalcopyrite, with few alteration products. No distinct vein was found, the ore occurring mainly as a replacement of the country rock in disseminated lenses and strings. A little gold is reported to be associated with the copper, but neither its value nor its relation to the copper mineralization was learned.

Although of no commercial value, the occurrence of copper sulphides in a pink granite, with rather large feldspar crystals, on the upper part of Peace River 2 or 3 miles above camp B13, is noted as giving a suggestion of the time of introduction of some of the copper mineralization. At this place there is only a little copper, but it seems to have been brought in contemporaneously with the granite. As there is no evidence at the other places already described of the age of the mineralization, this occurrence becomes significant.

From the preceding accounts of the meager amount of development work on copper lodes it is evident that no deposits of value are known. In part this may be due to lack of thorough investigation, but it is believed to be due in the main to the absence of cupriferous veins. Therefore, although valuable copper may be discovered in the future, the present conditions do not warrant search unless the enterprise is undertaken with the knowledge that the chances are against rather than in favor of success.

COAL RESOURCES.

Wherever the Cretaceous sediments are extensively developed throughout Alaska there are indications of coal. Some of these croppings in the area under discussion have been prospected and claims staked. Field examinations of some of the Alaskan coal deposits along Yukon River have been recently completed by Atwood, but the results have not yet been made available. Manuscript notes of the facts gathered by him concerning the Nulato region have, however, been furnished and have been of service in preparing the following paragraphs.

Fossils have not been found at many of the coal prospects and it is impossible to refer the various beds definitely to their proper geologic horizons. Closer correlations therefore than that the coals belong to the Upper Cretaceous will not be attempted, although it is believed that most of the deposits belong to the lower rather than the higher part of this series. One exception, in which the material is a very woody lignite, seems to be of much more recent age and is provisionally called post-Tertiary, mainly on account of its physical character.

For convenience of description a geographic order will be adopted. According to this plan, the deposits have been divided into, first, those occurring in the Yukon River drainage basin, and, second, those either in regions draining into Norton Bay or in Seward Peninsula.

YUKON BASIN.

The most eastern locality where coal has been prospected in this part of the Yukon basin is at Nahoclatilten or Louden, west of the mouth of the Melozitna. A description of these coals by Collier is as follows:[a]

Two beds of coal were seen by the writer at this place, and two more are reported to have been uncovered in prospecting. The largest observed seam has a thickness of 1 foot. Below this seam there are about 5 feet of bony coal or coaly shale with stringers of coal. There are reported to be 3 smaller beds in the foot wall, each having a thickness of 10 inches. Owing to the apparent rather intense folding of these beds, it is impossible to place much reliance on these statements.

The coal in the 1-foot seam is not crushed, although the beds are much disturbed in position. The following analysis shows it to be a bituminous coal of good quality. It is reported to have given satisfactory results in a blacksmith's forge.

[a] Collier, A. J., The coal resources of the Yukon, Alaska: Bull. U. S. Geol. Survey No. 218, 1903, pp. 47–48.

Analysis of coal (No. 241) from 1-foot seam 5 miles above Nahoclatilten.

[Analyst, E. T. Allen, U. S. Geol. Survey.]

	Per cent.
Water	6.88
Volatile combustible matter	41.82
Fixed carbon	48.93
Ash	2.37
	100.00
Sulphur	.65
Fuel ratio	1.17

Coke slightly coherent.

These coal beds have been known for several years, and various attempts have been made to open here coal beds of commercial importance, but thus far no seams thicker than 12 inches have been found.

No other coal prospects have been noted lower down on the Yukon until about midway between the mouth of the Koyukuk and Nulato. A mine, called from its owner the Pickart mine, was noted by Schrader in 1899; it is therefore one of the oldest coal mines in Alaska. According to Collier:[a]

At the Pickart mine one coal seam has been exploited which strikes N. 75° E. and dips 35° N. Two rolls, or horsebacks, are reported to occur in the floor of the coal bed. Whether these are in the nature of faults due to movement of strata along the coal bed or irregularities in deposition of the sediments constituting the floor the writer was unable to determine. Near these rolls the coal shows considerable crushing, which suggests that the roll is formed by deformation. The Pickart coal bed has a thickness of 30 inches at a distance of 300 feet from the entrance to the mine, but near one of the rolls above referred to the seam measured only 18 inches. Mr. W. E. Williams, manager of the Pickart mine, reports that in mining this coal a roll was encountered in the workings above the coal mine gangway in which the floor of the bed was raised up, pinching the coal down to a knife-edge thickness. The roll extended in a nearly straight line and approached the gangway at a rate of about 1 foot in 20. On cutting through this roll good coal was found.

Analyses of the coal from near this mine published by Collier are as follows:[b]

Analyses of semibituminous coking coal on the Yukon.

[No. 1 from 12 miles above Nulato, on the Yukon; analyst, George Steiger, U. S. Geol. Survey. Nos. 2 and 3 from Pickart mine, on the Yukon; analyst, E. T. Allen, U. S. Geol. Survey.]

	1.	2.	3.
Moisture	0.86	1.02	1.64
Volatile matter	25.75	27.33	24.98
Fixed carbon	66.51	65.03	58.18
Ash	6.88	6.62	15.20
Sulphur	....	.56	....
Fuel ratio	2.22	2.37	2.32

[a] Collier, A. J., op. cit., p. 50.

[b] Idem, p. 62.

In 1907 this mine was visited by Atwood, who reports that no work had been in progress for several years. According to him there are at least four thin seams of coal stratigraphically higher than the one the mine was opened on. These upper beds are only from 6 to 8 inches in thickness, and are associated with carbonaceous shales, which show frequent signs of cross-bedding and ripple marks.

About a mile above Nulato, Collier noted a prospect hole sunk in the sandstones called Nulato sandstone by Dall. The section exposed showed 2½ feet of bony coal with several bands of clay. One 6-inch bed of clean coal was uncovered and, it is reported, was used to some extent for blacksmithing at Nulato. There has been no recent work at this prospect, and it is evident that the seam is too thin to invite further investigation.

Four miles below Nulato, in the same sandstone in which the other prospects already described occur, is a coal bed that has been opened to a small extent. This mine is locally known as the Busch mine. No mining has been done here for several years. Atwood, when he visited the prospect in 1907, reported that the slope had caved so as to make the mine inaccessible. According to Collier, at the time of his visit in 1903:

In the tunnel, which extends about 40 feet, large bodies of crushed coal 4 to 5 feet in thickness are exposed. The coal is regarded as bituminous, having a fuel ratio of 1.76 and a water content of 11.17 per cent. The high percentage of water is probably due to decomposition of the coal in the croppings. No coal has been produced.[a]

Aanalysis of coal from Busch mine, 4 miles below Nulato.[b]

[Analyst, E. T. Allen, U. S. Geol. Survey.]

Moisture	11.17
Volatile matter	29.48
Fixed carbon	52.02
Ash	7.33
	100.00
Sulphur	.44
Fuel ratio	1.76

Coke, noncoherent.

About 5 miles below the Busch prospect is the Blatchford mine, which is also abandoned. Collier reports:[a]

One workable coal bed has been opened at this place. This bed has been crushed and sheared by the movements of the inclosing strata, making it very irregular. Large masses 8 feet in diameter have been found and mined out, showing that before it was disturbed the coal bed probably had considerable thickness. The coal has a tendency to break up into fine pieces, though it is

[a] Collier, A. J., Bull. U. S. Geol. Survey No. 213, 1903, p. 281.

[b] Collier, A. J., The coal resources of the Yukon: Bull. U. S. Geol. Survey No. 218, 1903, p. 53.

a bituminous coal having a fuel ratio of 3.30, the highest of any coal on the Yukon, and a water content of 1.36 per cent. The ash is only 2.22 per cent, making it, by approximate analysis, the best coal seen by the writer on the Yukon River.

This mine has no visible development or permanent equipment. The workings lie below the level of the river and the entrance is covered with water during the summer months, so that it can be worked only in the winter after the freezing of the river, where the ice filling the upper workings must be mined out before the coal can be reached. The mine has probably produced about 300 tons of coal.

The Williams coal mine is located on the west side of the Yukon just south of the mapped area. It has been more extensively developed than any of the mines already described, but as it does not come within the area covered by this report, description will be omitted except to state that in a broad way conditions are the same there as in the other prospects.

NORTON BAY BASIN AND SOUTHEASTERN SEWARD PENINSULA.

Coal has been reported at a number of places along the eastern shore of Norton Bay, but so far as known no beds of a sufficient size to allow profitable mining have been discovered. Dall mentions a 2-foot bed of shale and lignite, possibly Kenai in age, on Ulukuk River, a tributary of the Unalaklik from the north.[a] It was reported to have no commercial value. Brooks[b] states:

Capt. D. H. Jarvis informed the writer that some very good-looking coal had been found near Unalaklik Cape near the eastern shore of Norton Sound. These [beds] probably belong to the same series described by Dall.

Several openings have been made near the mouth of the Koyuk on the western side close to camp B17. Unfortunately the shafts were not in condition to be examined, and the only information gained was from a study of the material on the dump, as there are no exposures of the coal-bearing rocks in the neighborhood. Although lignitic material was found at this place, several years of desultory prospecting have failed to disclose a workable bed. The shafts show a series of sandstones and clays which have weathered badly on the dump and appear much less consolidated than the average sandstones near Nulato. It is understood that during 1909 the company formerly interested in this claim abandoned the enterprise.

In this same region coal float has been found on Coal Creek and claims have been recorded, but none of them was being prospected in 1909. Probably little of value was found as the series is without doubt similar to that near camp B17.

[a] Dall, W. H., Correlation papers, Neocene: Bull. U. S. Geol. Survey No. 84, 1892, p. 246.

[b] Brooks, A. H., Coal resources of Alaska: Twenty-second Ann. Rept. U. S. Geol. Survey, 1902, pt. 3, p. 560.

Mendenhall[a] says concerning his investigation in southeastern Seward Peninsula:

> The only rocks encountered in the reconnaissance likely to carry coal are the sediments supposed to be of Tertiary age outcropping on the Tubutulik and Koyuk rivers in narrow belts. No direct evidence of the presence of this mineral was secured on the Koyuk, but along the river bank associated with the sandstone outcrops on the Tubutulik are numbers of small pieces of bright compact coal seemingly of good quality.

The presence of this coal float has long been known to prospectors but so far no beds that would warrant investigation have been discovered.

As previously stated one locality was visited in 1909 where there is a woody lignite of relatively recent age and differing from those previously described. This exposure is on the Rathlatulik, a tributary of Fish River, about 10 miles above the junction of the streams. A shallow pit has been sunk here and slightly carbonized fragments of wood found. Underneath this layer of woody material is a blackish-green calcareous muck which is nearly flat or has a slight slope toward the east. A cross section of the valley at this point shows a low bench about 5 feet above the water, succeeded on the east by another bench 15 feet higher 100 paces beyond the stream and separated from the lower bench by a steep cliff. All the material from the stream to the top of the 15-foot cliff is well-rounded gravel. Several abandoned river beds are found on the lower bench.

The coal is not over 18 inches thick and is of poor quality, having advanced little beyond the wood stage. Resin is abundant in many of the samples of this material. No tests of the coal were made, but from its physical character it does not seem possible that it could be used for fuel except very locally. No accurate estimate of the amount of material available could be made without further exploitation, but it is believed to be of very slight extent and not of sufficient value to warrant further development.

CONCLUSIONS REGARDING THE COAL RESOURCES.

In the foregoing paragraphs the places where the coal-bearing rocks have been prospected to some extent have been described with the object of showing the general character of the known coal deposits. Indications of coal have been noted at many other places, but the types are essentially similar and do not merit specific description. There are certain conclusions that may be drawn from the facts that may save prospectors from spending their time unprofitably in the search of coal. Coal will be found only in the areas of Cretaceous sediments. No economically important beds are to be expected in

[a] Mendenhall, W. C., A reconnaissance in the Norton Bay region, Alaska, in 1900, a special publication of the U. S. Geol. Survey, 1901, p. 214.

the unconsolidated alluviums such as those in the Fish River basin on the Rathlatulik. From the fact that so far there is no productive mining on any of the coal-bearing rocks outcropping along the Yukon within the mapped area, it seems improbable that workable beds in the same series of rocks will be developed in the immediate future in the more remote regions where transportation facilities and markets are wanting. Although thicker beds may be found here and there, the additional cost of transportation for each mile that the deposit lies back from the river or from some other cheap avenue of communication increases much more rapidly than the thickness of the bed could be reasonably assumed to increase. It is improbable, therefore, that workable coal, where it is not now known, will be found in the Nulato-Council area.

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